International Journal of Computer Science Engineering
and Information Technology Research (IJCSEITR)
ISSN(P): 2249-6831; ISSN(E): 2249-7943
Special Edition, Apr 2015, 79-106

CONTEXT AWARE WAVELET BASED IMAGE FUSION IN WIRELESS SENSOR NETWORKS USING COGNITIVE AGENTS

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ABSTRACT

Wireless sensor networks (WSNs) can be used in monitoring disaster management, military operations, agriculture, building structures, etc. Fusion of images has been of great interest and challenge in WSNs. Image fusion involves fusing of two or more collected images after elimination of redundant information based on the context. This paper proposes a cognitive agent based context aware image fusion scheme for WSNs. The contexts considered are: general (simple and non-critical) and critical object detection. The work employs sensor node and sink node agencies. Each agency em- ploys a set of static and mobile agents to perform dedicated tasks. The proposed scheme works in following steps. (1) Sensor node agency performs context sensing and context interpretation by using BDI (Belief, desire & intention) model and the interpreted context is sent to the sink node. (2) Sink node agency receives the context information and generates the mobile agents (called fusing agents) which are responsible for fusion of images from active sensor nodes. (3) Mobile agent roams around the network, visits all the active nodes and fuses the image by using wavelet transform. (4) Mobile agent returns the fused image to sink node agency. The scheme is simulated to test the operation effectiveness. The parameters analyzed are fusion time, mean square error, throughput, dropping rate, agent overheads, bandwidth requirements and node battery usage.

KEYWORDS: Wireless Sensor Networks, Context-Aware, Software Agents; Cognition, BDI, Image Fusion

INTRODUCTION

Wireless Sensor Networks (WSNs) consist of small nodes that have sensing, computation, and wire- less communications capabilities. Due to recent technological advances, the manufacturing of small and low cost sensors has become technically and economically feasible. A tiny sensor node communicates within a short distance and collaboratively works to fulfill the application specific objectives of WSNs [1] [2]. Large number of sensors can be networked in many applications that require unattended operations. These sensors have the ability to communicate either among each other or directly to an external Base Station (BS), called as sink. The deployment of more number of sensors allow sensing over larger geographical regions with greater accuracy. Using conventional methods of data gathering and processing in WSNs could lead to some of the problems like energy consumption, redundant data transmission, increased latency, bandwidth overheads, etc. The inclusion of context-awareness in WSNs can solve these problems to a greater extent. Context can be defined as that which surrounds, and gives meaning to something. It can be identity, activity, location or time. Context is usually used to represent the information type in a system. In order to conserve the network life time of the WSN, context aware computing and software agent technology paradigm together can be used.

The introduction of the context-awareness [3] in various applications helps to retrieve the information quickly. According to [4], a system is context-aware if it uses context to provide relevant information and service to the user. Context based information gathering for WSNs need to have proper information and measure of the context what we are using to represent the system. Context-Aware computing mainly helps to get the relevant information from the environment, which in turn saves the energy consumption. WSNs can be used for monitoring in various applications such as agriculture, disaster areas, health care, military, buildings, forests, animals, industrial control, etc. It has been found that WSN have great challenge to monitor the militant activities in the battle field. WSN's can be used for various applications in military such as, army movement monitoring, ammunition monitoring, regulating friendly troops, etc. The sensors must be equipped with various visual aids, so that they can generate some really interesting and very useful data.

The sensor nodes may be equipped with multi-resolution camera's. Apart from the basic sensor nodes which collect scalar data, these sensor nodes generate huge amount of data, which has lead to a new challenge for the sensor nodes. As these nodes collect huge amount of data, the bandwidth requirements for such networks are also high, thus these networks must be designed and deployed in such a way that they should make use of new improved and sophisticated processing and computation technologies. As these WMSN's requires sophisticated processing, the main challenges in such kind of networks is the energy consumption. Most of the WSNs will have lots of redundant data, hence this redundant data can be processed and aggregated in an efficient manner which can in-turn reduce the energy consumption and can prolong the lifetime of the battery. Fusion of data is one of the method which can eliminate the redundant data's among WSNs. Fusion can be done at many levels and there are many algorithms available for the fusion process.

Software agents can be employed for information fusion to prolong the network life time by identifying the redundancy in information. Agents can be static or mobile. Static agents reside at particular location and perform tasks autonomously either by interacting with user or other agents at environ- ment in the network and perform autonomous tasks by collaborating with other mobile/static agents or users. Mobile Agent based applications mainly fall in the areas like: network management, electronic commerce, wireless multimedia sensors, grid computing and grid services, distributed data mining, multimedia, human tracking, security, etc.

In this paper, the proposed cognitive agent based context aware image fusion addresses the following issues: (1) gathering context aware information from the target by using cognitive agents; (2) preprocessing of the data at a node to eliminate the redundant data transmission, (3) classification of gathered information as critical and non critical information based on the context; (4) employing 1-level and 2- level wavelets to fuse images in order to eliminate redundancy that saves network bandwidth and energy;

- applying 1-level wavelet to fuse image and reduce the delay of critical information transmission and;
- mobile agent is embedded with wavelet based image fusion code that roams around the network for information fusion.

Related Works

The military requirements for flexible wireless sensor networks has been provided in [5]. It describes the evolution of military sensor networking devices by identifying three generations of sensors along with their capabilities and also presents some of the existing developer solutions. It also gives an overview of some of the previous works and challenges in order to achieve fully flexible, security proved, ad-hoc, self-organizing and scalable military sensor networks.

The work presented in [6] investigates the design trade-offs for using WSN for implementing a system, which is capable of detecting and tracking military targets such as tanks and vehicles. Such a system has the potential to reduce the casualties incurred in surveillance of hostile environments. The system estimates and tracks the target based on the spatial differences of the target object signal strength detected by the sensors at different locations. In [7] [8] a survey of mobile agent based applications is presented.

The work presented in [9] considers the trade off between the increase in the data aggregation re- quired to reduce the energy consumption and the need to maximize the information integrity. A position- based aggregation node election protocol for wireless sensor networks, where aggregation node election is done to support asynchronous sensor network applications [10]. Sensor readings are fetched by the base stations after some delay. It uses the position information of the nodes to determine which of them should become aggregator. It also ensures the parameters like load balancing, intra and inter-cluster routing, aggregator-to-aggregator, base station-to-aggregator and aggregator-to-base station communications.

A load balancing data gathering algorithm that forms different groups of sensor nodes is described in[11]. A technique to extend the WSN operational time by organizing the sensors into a maximal number of disjoint set covers that are activated successively is presented in [12]. Active sensors are responsible for monitoring events and for transmitting the collected data, while nodes from all other sets are in a low-energy sleep mode. In [13], the minimum data aggregation time under collision-free transmission model is presented. The objective is to search the technique that schedules data transmission and aggregation at sensors so as to send the data in the minimal time.

The problem of finding a route for a mobile agent that incrementally fuses the data as it visits the nodes in a distributed sensor networks, has been considered in [14]. In applications like target classification and tracking, the order of nodes visited along the route has a very high impact on the quality and cost of fused data. The work presents a simplified analytical model for a distributed sensor network and formulates the route computation problem in terms of maximizing an objective function, which is directly proportional to the received signal strength and inversely proportional to the path loss and energy consumption.

The work given in [15] presents a method for fusing of the sequences of images obtained from multimodal surveillance cameras and subjected to distortions typically for WSNs. The scheme uses the Structural Similarity Measure (SSM) to measure a level of noise in regions of a received image in order to optimize the selection of regions in the fused image. Dual-Tree Complex Wavelet transform (DT- CWT) is used in the algorithm for region-based image fusion to fuse the selected regions. SOAR [16] is an excellent example for automated flight control and battlefield simulation which is developed by using cognitive agent based systems. The work mainly describes the military application scenario, where there is no predefined knowledge.

University XXI project [17] is an agent system for battlefield simulation. The system mainly focuses on tackling the cooperation among the large units (troops, obviously at a battalion level). The work uses some of the predefined rules. The system described is reactive but not adaptive. DARPA/DLA is a five year project which initiated the Advanced Logistics Program (ALP) [18]. The project developed a technology that supports an end-to-end logistics system with automatic plan generation, execution monitoring, end-to-end movement control.

Our Contributions

The work proposes an agent based scheme which performs context aware image fusion to eliminate the redundant data in WSN's. The proposed scheme considers contexts driven by a sensor node and sink node. The contexts such as non-critical (simple) and critical (emergency) object detection are node driven, whereas on-demand fusion based on sensing time (day/night) and the user queries is sink driven. The agencies used in the scheme are sensor node and sink node agency. Each agency employs a set of static and mobile agents to perform dedicated tasks. A mobile agent is a computer entity/software capable of reasoning, which will use the network architecture/infrastructure to run in a remote site, search and collect the information, cooperate with others and then return to the generation site/home site after completing the assigned tasks. Sensor node agency performs context sensing and context interpretation based on the sensed image and sensing time. It comprises of node manager agent and context agent. Sink node agency comprises of sink manager agent and fusing agent. The proposed scheme works in following steps. (1) A context at the sensor node activates context agent that gathers the context from the target. (2) Node manager agent interprets the context and passes the context information to sink node by using flooding mechanism. (3) Based on the context, sink manager agent triggers the fusing agent. (4) Fusing agent roams around the network, visits active sensor nodes, fuses the relevant images by using wavelet transform and sends the fused image to sink.

Our contributions are as follows. (1) Employing cognitive agents at the sensor nodes to provide the cognition capabilities, which interpret and deliver context aware information in reliable way, (2) intelligent decision making based on context, (3) wavelet based image fusion code is embedded in mobile agent for image fusion, and (4) fused image transmission reduces bandwidth requirement.

The rest of the paper is organized as follows. Section 2 presents image fusion by using wavelet transform. Section 3 discusses software agents. In section 4, the proposed work has been described with context-aware information fusion and mathematical models. Simulation model and performance parameters are discussed in section 5. Section 6 discusses results. Conclusion and future scope has been presented in section 7.

Wavelet-based Image Fusion

Image fusion is required, whenever the images are acquired from different modalities and different capturing techniques [19]. Image fusion is a process in which two or more images are combined together into an single image retaining all the important features of each of the original images.

Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale [20] [21]. Wavelet transform fusion is most basic and common form of transform image fusion technique. In all transform domain fusion techniques, all the transformed images are combined in the transform domain by using a defined fusion rule and are transformed back to the spatial domain to give the fused image.

In image processing one of the major problem is edge detection, which involves detecting abrupt changes. Wavelets are basically well suited and adaptive for such phenomenon. Advantages of wavelet transforms are as follows: It retains all the spatial components; all the spectral qualities of the image are well preserved; makes use of both frequency and spatial space together which can be more efficient; and multi-resolution analysis feature is more useful.

Wavelet transform fusion is defined by taking into account the wavelet transforms ω of two images $M1(x, y)$ and $M2(x, y)$ along with a fusion rule φ. Then the fused image M(x,y) is reconstructed by computing the inverse wavelet transform $\omega-1$.

$$M(x, y) = \omega{-1}(\varphi(\omega(M_1(x, y)), \omega(M_2(x, y)))) \quad (1)$$

All multi-resolution fusion schemes are motivated by the human visual system, as they are sensitive to local contrast changes, that is edges or corners. In the case of wavelet transform fusion, all respective wavelet coefficients from the input images are combined by using the fusion rule. Since wavelet coefficients having large absolute values contain the information about the salient features of the images (edges and lines), a good fusion rule is to take the maximum of the corresponding wavelet coefficients. The maximum absolute value within a window is used as an activity measure of the central pixel of the window. A binary decision map of the discrete wavelet transform (DWT) is constructed to record the selection results based on a maximum selection rule. Rather than using a binary decision, the resulting coefficients are given by a weighted average based on the local activity levels in each of the image's subbands.

Figure 1 depicts image fusion by using DWT. DWT is first performed on each source image, then a

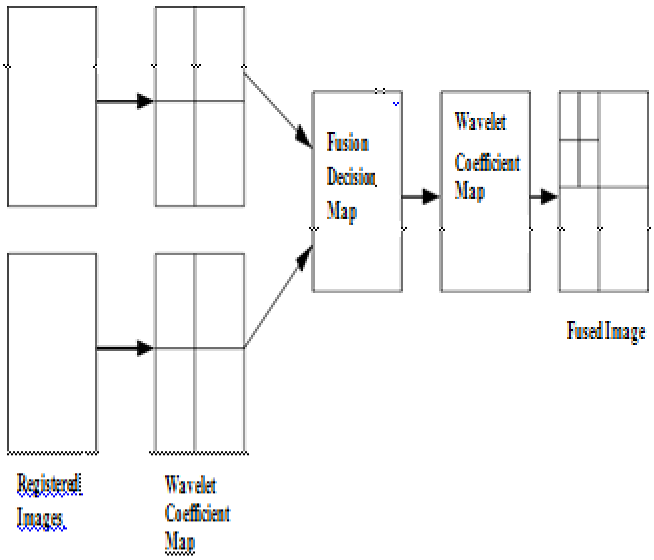

Figure 1: Fusion of Images Using Discrete Wavelet Transform (DWT)

Fusion decision map is generated based on a set of fusion rules. The fused wavelet coefficient map can be constructed from the wavelet coefficients of the source images according to the fusion decision map. Finally the fused image is obtained by performing the inverse wavelet transform. When constructing each wavelet coefficient for the fused image, we have to determine which source image describes the coefficient in a better way. This information will be kept in the fusion decision map. The fusion decision map has the same size as the original image. Each value is the index of the source image which may be more informative on the corresponding wavelet coefficient and thus make a decision on each coefficient. Assume that node 'i' and node 'j' have the common information to be sent to the sink node. In order eliminate the common information between the neighboring nodes, a fusion process is adopted. Multi sensor image fusion by using wavelet transform is given by the equations (2) and (3).

$$F\,i(u, v) = DWT\,(fi(x, y)),\ Fj\,(u, v) = DWT\,(fj\,(x, y)) \quad (2)$$

$$F\,ij\,(u, v) = fusionrules(Fi(u, v), (F\,j\,(u, v)) \quad (3)$$

The fused image is given by the equation(4)

$$F\,ij\,(x, y) = idwt(Fij\,(u, v)) \quad (4)$$

where, **f*i*(x,y):** Image of sensor node 'i', **f*j* (x,y):** Image of sensor node 'j', **f*ij* (x,y):** Fused Image of sensor node 'i' and sensor node 'j', **F*i*(u,v):** Node 'i' image in transform domain, and **F*j* (u,v):** Node 'j' image in transform domain.

SOFTWARE AGENTS

Software agents are the programs that execute autonomously on behalf of a user or a process. The agents can be classified into single-agent and multi-agent systems. Single-agent systems do not cooperate or collaborate with other agents in the system or environment whereas multi-agent systems such as distributed agents and mobile agents cooperate and collaborate to achieve specified task. Mobile agents move around the network or environment by executing at remote sites and interacting with other static/mobile agents to achieve their specific goals. A static agent executes only on a host where it is situated. Agent based systems allow flexibility, adaptability, asynchronous communication and intelligent decision making. The infrastructure on a host provides an agent platform that provides agent creation, agent interaction, directory of services, persistence, communication, security and navigation services.

When adopting agent technology for real-world applications, it becomes necessary to have an approach of multiple agents. Much of the promised flexibility of agent technology is based on the dynamic organization of agents and versatile communication. Agents in a multi-agent system are responsible for areas of the environment, and basically agent society has multiple layers in its structure. These agents exchange information directly via messages or indirectly via changes in the environment. As messages are more controllable, they are typically used. Sophisticated negotiations are an important benefit of using agents to construct software systems. Negotiations are constructed from series of messages that agents send to each other. Typically, agents try to coordinate their actions with negotiations, but a competitive approach is also possible. Presently in multi-agent systems, cognitive agents and BDI agents are interesting research areas, basically both of them are the form of intelligent agents, which co-ordinate with all other agents in the environment and among themselves. BDI stands for (B)eliefs, (D)esires and (I)ntentions, which are mental components present in an agent architecture[22].

Cognition comprises phenomena like problem solving, decision making and learning. A cognitive agent is defined as a technical system embedded in a complex environment, that gathers and processes information in order to act in and thereby alter the environment by own behavior. In other words these are the agents that processes the information according to a model of human cognition. There are several reasons why cognitive agent systems are useful: (1) The actions of cognitive agents are more human- like and are understandable to the people. (2) The knowledge of the agents are readily obtainable from human experts in the same field of work and (3) The agents internal reasoning and thought processes are easier to analyze and debug. Because of these properties, the application of cognitive agents are of special interest in industrial applications and many more too. Studies of behavior of cognitive agents are defined in-terms of rational balance between its mental attitudes.

Autonomous agents are an important development towards the achievement of many of promises in artificial intelligence. Among the many proposed cognitive agent architectures, Rao and Georgeff's [23] is a well known BDI agent model that has mental attitudes of an agent. Multi-context systems are devised by Giunchiglia and Serafini [24] to structure knowledge into distinct theories. This allows to define complex systems with different formal components and the relationships between them. In short, belief represents the agents knowledge, desire represents the agents goals and intention lends deliberation to the agent.

PROPOSED WORK

This section provides the complete description of the proposed work; network environment, different computational models such as, correlation model, histogram model and image signal strength model, agencies and algorithms.

Network Environment

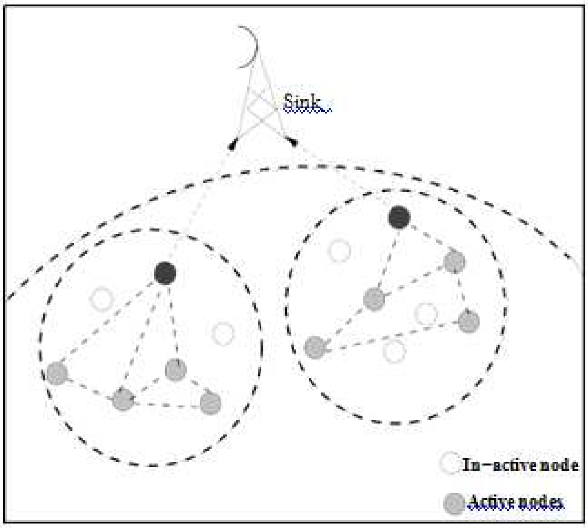

Figure 2: Network Environment

Network environment is shown in figure 2. It consists of heterogeneous sensor nodes and a sink node (also called as end node that receives information). Sensor nodes are geographically distributed and collect data periodically. Sensor node comprises of an agent platform with static and mobile agents, camera and other sensory devices such as light condition, temperature, humidity, etc. A sensor node is said to form a cluster around it based on the communication range. A sensor node has several channels with different sensory devices connected to it. Every sensor node of WMSN has predetermined value of the signal strength. Once the information is sensed by sensor node, it compares the information signal strength with predetermined value; if it is greater (if the deviation is more), a message is sent to sink node by using flooding protocol announcing itself as an active node. Flooding is a technique used for routing in WSNs. In flooding, each node receiving data or management packet repeats it by broadcasting, unless either a maximum number of hops for the packet is reached or the destination of the packet is reached. Flooding is the reactive technique and the it is important to note that it does not require costly topology maintenance and complex route discovery algorithms.

Definitions

This section provides definitions of some terms used in describing the proposed work.

- Sink Node: It is an end node, which can be considered as a Base Station. Sink node is responsible for collecting information and coordinating overall processing of the information, It has its own knowledge base which is called as Sink Black Board (SBB). SBB has all the information about the sensor node such as, node id, geographical location, communication range, bandwidth required etc. It mainly generates the fusion agent, which is required for fusion.
- Critical information: An image sensed by the sensor node which is a critical object (such as gun, enemy

movement, enemy vehicles, etc. in military). Based on the sensed image importance, context will be interpreted as critical and the sink node is informed.

- Non-critical information: This relates to the less critical information such as, lighting conditions, fog, temperature, etc. Such information may be fused on-demand by the sink node.
- Emergency context (critical context): Whenever the sensed image matches with any one of the critical images in the database of a sensor node, then we define it as an emergency context. This information will be sent to the sink node, which triggers fusion process with a single level wavelet fusion code.
- Simple context: If the sensed image does not match with any one of the critical images in the knowledge base of sensor, then it is considered as simple context. Once simple context has been interpreted; information will be sent to sink node which triggers fusion process with two level wavelet fusion code.
- Belief set: It is the belief set generated by sensor node based on the sensed parameters $\psi 1$, $\psi 2.\psi n$
- and actions taken.
- Beliefs: It is the database comprising of belief sets generated by sensor node.
- Image signal strength: It is entropy difference between the two considered images.
- Image correlation: It is the degree of similarity between the images.

Mathematical Models

Wavelet transform has been used for image fusion as it has got the advantages as described in the section 2. For emergency context, we use single level wavelet fusion code and for simple context we use two level wavelet fusion code. In this section, we present image signal strength model, correlation model and context interpretation model. We assume gray scale images in our work.

Image Signal Strength Model

The notion of entropy may be used to estimate the information content. For an image, the simplest idea is to create these states that correspond to the possible values in which all pixels are involved. The image entropy is given by equation (5).

$$H = -\sum_{k=0}^{255}(P_k \log_2 P_k) \tag{5}$$

Where P*k* is the probability of gray level 'k', k=0,1,2,3,,255, assuming an 8-bit image. Equation (5) represents the information content of an image.

Image signal strength is measured by estimating the entropy of difference between previous and present image stored in the sensor node. The difference between the images is given by equation (6).

$$\Delta Ij = Ij - I_0 \tag{6}$$

Where Ij is the present image , $I0$ is the previous image of the node. Entropy is then applied to difference between images to measure the change in information, i.e., image signal strength estimation as given in equation (7).

$$Pj = H(\Delta Ij) \qquad (7)$$

Where *Pj* is difference image and H denotes entropy. Only the gray scale information of the images is used to calculate the image entropy. A threshold signal of the image is considered to find out the required signal strength where it is defined as the amount of information change between present and previous image. This facilitates to decide the active mode of a sensor node. If *Pj* is greater than threshold, then node is considered to be active otherwise inactive.

Correlation Model

The correlation between two images (cross-correlation) is a standard approach to feature detection. The model used for calculation of the correlation between two images directly can be given by equation (8). Suppose matrix A has dimension (Ma,Na) and matrix B has dimension (Mb,Nb), then 2-D Cross-

Correlation is given by equation (8)

$$C(i,j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m,n) * Conj(B(m+i,n+j)) \qquad (8)$$

Where 0≤i≤Ma+Mb-1 and 0≤j≤Na+Nb-1.

Context Interpretation Model

For a given image I, the histogram *HI* is a compact summary of an image. A database of images can be queried to find the most similar image to I, and can return the image with the most similar histogram *HI* . Typically histograms are compared by using the sum of squared differences or the sum of absolute value of differences. Thus most similar image to I would be the image I' given by minimizing equation (9).

$$||H_I - H_I'|| = \sum_{k=0}^{255} (H_I - H_I') \qquad (9)$$

In the image registration, since there are two images, joint entropy will be considered. Joint entropy measures the amount of information we have in the two combined images. The joint entropy *H(x,y)* can be calculated by using joint histogram of two images. If the images are totally unrelated, then the entropy will be the sum of the entropy's of the individual image (equation (10)). More the similar images, joint entropy will be lower compared with the sum of the individual entropy's.

$$H(A,B) \le H(A) + H(B) \qquad (10)$$

Based on the histogram values, the context interpretation is carried out. We fix some threshold histogram value, and then start comparing the sensed image from database. If the histogram value after comparison process is below threshold value then we say that this sensed image matches with the images in database and we classify this as an emergency context, else as simple context. And these information are transmitted to the sink node. Based on this context interpretation, the sink node will take necessary actions.

Agencies

In this section, we present the proposed agencies such as: sensor node agency and sink node agency. Each agency employs a set of static and mobile agents to perform dedicated tasks. Sensor node agency performs context sensing and context interpretation based on the sensed image and sensing time. It comprises of node manager agent and context agent. Sink node agency initiates fusion process and it comprises of sink manager agent and fusing agent.

Sensor Node Agency

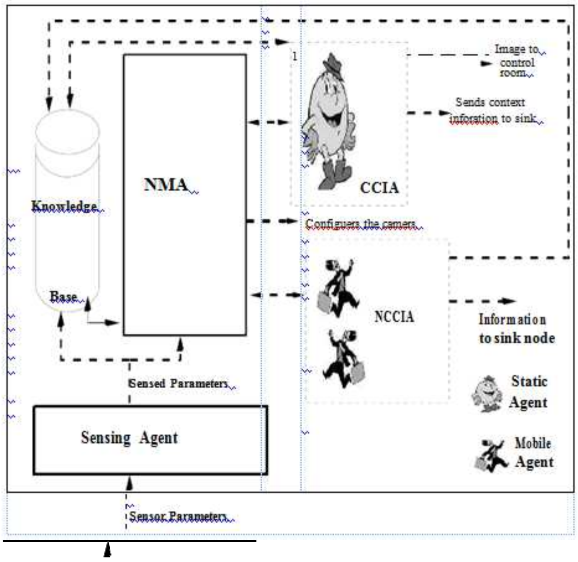

Figure 3: Sensor Node Agency

The various components of sensor node agency are shown in figure 3. The agency consists of a Knowledge Base (KB) - also called as NBB (Node Black Board), Sensing Agent (SA), Node Manager Agent (NMA) and Critical Context Interpretation Agent(CCIA) and Non-Critical Context Interpretation Agent (NCCIA). SA, NMA and CCIA are static agents whereas NCCIA is a mobile agent.

Node-Black-Board (NBB): It consists of node id's, previously sensed images, sensing time, critical images (such as enemy dresses, their weapons, explosives, etc. in military), beliefs including neighbor

Table 1: Sensed Parameters for Building Belief Sets

Sensing Type	Sensed parameters
Image	(ψ_{s11}, t_1) (ψ_{s12}, t_2) (...) (.,.) (ψ_{s1n}, t_n)
Light conditions	(ψ_{s21}, t_1) (ψ_{s22}, t_2) (...) (.,.) (ψ_{s2n}, t_n)
Temperature	(ψ_{s31}, t_1) (ψ_{s32}, t_2) (...) (.,.) (ψ_{s3n}, t_n)
Fog conditions	(ψ_{s41}, t_1) (ψ_{s42}, t_2) (...) (.,.) (ψ_{s4n}, t_n)

Nodes list, available bandwidth and information regarding past events. Beliefs are also updated by the current desires and intentions. It has all the information required by a sensor node and is dynamic.

Sensing Agent (SA): It is a static agent that senses images and other parameters through sensory devices periodically regarding the environment and updates the NBB as well as informs NMA. It can also be triggered as and when required on-demand by the sink node.

Node Manager Agent (NMA): It is a static agent based on the BDI model that runs in the sensor node. It is mainly concerned with the creation of the NBB, controlling and coordination of the agency. It creates two types of agents known as Critical Context Interpretation Agent (CCIA), which is a static agent used in context interpretation and Non-Critical Context Interpretation Agent (NCCIA), which is a mobile agent used for storage and fusion of non-critical information. SA is triggered by NMA whenever the node wakes up. NMA makes decision on sensed information either as critical information or non- critical information by using image signal strength model. After the NMA has made its decision, it generates CCIA for further context interpretation and also generates NCCIA for fusion of non-critical information. The belief set, desires and intention generation is the other important aspect of NMA. This agent updates the belief sets and other data according to the sensed parameters in the knowledge base. The sensed parameters are as shown in the table 1, where $\psi sij, tn$ denotes 'i'th parameter sensed with 'j' values beginning with time *tn* in a given interval.

The BDI architecture presents following benefits: WSN's exhibit dynamic changes in the environment and their parameters too. BDI agents have the capability of quickly adapting to such environment; the sensing capabilities and the sensing parameters may be many and can keep changing, therefore the beliefs regarding the environment can be regularly updated by using BDI architecture; autonomous de- cisions can be made based on the criticalness of sensed parameter.

The belief generation and action selection is done as follows.

- In the context of the BDI-frame work for the proposed work, here we will use AgentSpeak(L) to model the BDI system [25]. We will follow all the notations and expressions of the AgentSpeak(L) agent. An AgentSpeak(L) agent consists of the belief set and plan clause.
- In general the belief set $\{Bn\}$ can be formalized as $Bn = \{\psi s1n, \psi s2n, ..., \psi snn, Cn\}$. Where *Cn* is criticalness of information which is either 1 or 0. NMA calculates the image signal strength of the sensed image out of all other sensed parameters using the model given in section 4.3. NMA takes the decision *Cn*. Cn =1 indicates change in the entropy (critical) whereas Cn=0 means no change in the entropy (non-critical).
- Based on these belief sets B_1, B_2, ...Bn, the NMA's plan clause can be given as

$$goal:\{B_1 \wedge B_2, ..., \wedge B_n \leftarrow C_1....C_n\} \tag{11}$$

Where *Bn* is the belief and *Cn* is an action.

Basically, AgentSpeak model works in the following steps.

- The agent selects an event that has occurred based on sensor status and images.
- The agent generates the plans with matching conditions, where the matching factor is defined by the NMA or the user.

- Among all the plans, agent identifies the plan with satisfying preconditions.
- The plan is then added to the intention stack. This intention stack is executed by popping out topmost plan and performing the first *Ci, if Ci* is event.

Let us say, Ψ = NMA plan set, Ψ*i* = *ith* plan clause, C = goal which triggers Ψ*i*, *BS* = the belief set {*B*1 V *B*2, ... V *Bn*}. We use Ψ*i*(*BS, C*) to denote the body of *ψi* and also assume that the plan

consists of number of action plans.

$$\Psi i(B_S, C) = \{(C_1(P\ ), C_2(P\ )), head(\Psi i(B_S, C) = (C_1(P\ ))), tail(\Psi_i(B_S, C) = (C_2(P\ )))\} \quad (12)$$

Where each action plan (*Ci*(*P*)) is a well defined action performed by the NMA i.e, if action selected is C_1 = critical information then NMA generates Critical Context Interpreter Agent (CCIA) and if action selected is C_2 = non-critical information then NMA generates Non-Critical Context Interpreter Agent (NCCIA). Both CCIA and NCCIA perform the actions as mentioned in below subsections.

Critical Context Interpretation Agent (CCIA): It is a static agent generated by NMA for interpreting the context. CCIA gets the sensed image from NMA and compares the sensed image with the images in

The NBB. A histogram is used for the comparison of the images as given in context interpretation model. Threshold for comparison is fixed (basically an intermediate value between high and low histogram value for a gray scale image) by the NMA. If the value after comparison of the images is below the threshold, then, the context is emergency type (i.e., image sensed is nearly same as that in the data base), else if the value is above threshold, then the context is interpreted as simple context (i.e., image sensed is nearly same as that in the data base). In case, where emergency context is detected, the corresponding information will be sent to the sink node. Sink node initiates fusion process using 1 level wavelet fusion code embedded in a mobile agent (called fusing agent). If simple context is detected sink node initiates fusion process with 2 level wavelet fusion code embedded in a mobile agent.

Non-Critical Context Interpretation Agent (NCCIA): It is a mobile agent which is meant for storage and fusion of the non-critical information. If NMA decides in favor of the non-critical information, which mainly relates to fog, temp and other environmental conditions. Then this information will be stored by the agent itself and updates NBB. If suppose user at the sink node requires the non-critical information, user communicates to NMA of sensor node for this information. NMA triggers NCCIA. Once the agent is triggered, it visits all other active nodes (collects the information present in the KB/NBB) and fuses only the non-critical information from active nodes and returns to sensor node. The information will be communicated to sink node. This helps in conserving the energy as it will deliver the non- critical information only as and when user wants it. It also helps the user to have an over all aggregated information about the environment.

Sink Node Agency

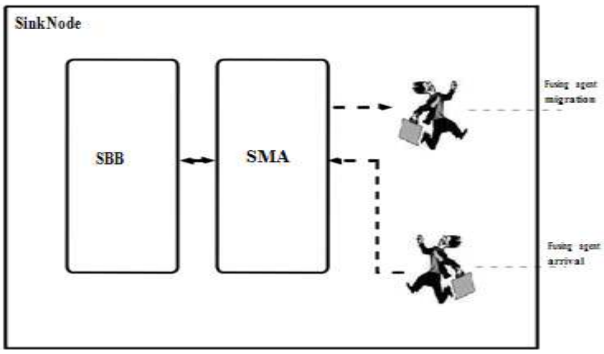

Figure 4: Sink Node Agency

Sink node agency is shown in figure 4. It comprises of Fusing agent (FA), Sink Manager Agent (SMA) and Sink Black Board (SBB).

Sink Manager Agent (SMA): It creates Fusion Agent (FA) and Sink Black Board (SBB), and is also responsible for synchronizing the actions of the agents in the agency. The agent monitors and updates the SBB continuously. Initiation of the image fusion process is done by SMA. SMA gets fused images from the target nodes in two ways: (1) based on the sensor node context (context driven) and (2) whenever user seeks (sink driven) fused information. SMA gets the sensor nodes location's information from the SBB. Based on the context, SMA triggers FA to visit the active nodes with the necessary fusion code, i.e., 1-level wavelet fusion code for emergency context and 2-level wavelet fusion code for simple context. We assume that routing table is already set and SMA provides this information to FA. The fused image is given to the user monitoring the network either by alert alarm or updated in the user database of images. Fusing Agent (FA): It is a mobile agent equipped with image fusion code (1 level and 2 level wavelet fusion code) that migrates from one active node to another active node (we assume the agent itinerary to be given by SMA) depending on the routing information provided by the SMA. The agent visits an active node, fuses the image, and moves to another active node along with the fused image. The agent will use correlation model, which is kept inside the sensor node to find the correlation of data/images. If the value is high it means that the data between the two nodes is highly correlated, then it will classify it as the fusion node and fuses the data, else it will classify it as non-fusion node and moves on to the next node until it visits all active nodes.

Sink Black Board (SBB): It is the knowledge base that can be read and updated by SMA. It stores the information about the node id, context information, time of sensing, image signal strength, bandwidth required to transmit the image of each active node, available network bandwidth, and geographical locations of the active nodes.

Algorithms

In this section, we present the various algorithm such as: sensor node agency algorithm, sink node agency algorithm and agent interactions.

Sensor Node Agency Algorithm

Nomenclature: (x, y) = Index value of the image, $H1$, $H2$=Entropy of present and previous images, Tth= Threshold of image signal strength, Pth =Percentage of similarity between previous and present image, $Nstatus$= Node status, $HD(x,y)$=Histogram value of the sensed/present image, $HP(x,y)$=Histogram value of the previous image.

BEGIN

- SA gathers the image, other parameters and time of sensing; generates the sensed event;
- NMA generates the options and checks the current belief sets for event presence; If belief set matches, then corresponding desire and intentions are generated, goto step 3; Otherwise, considers it as new belief set and generates desire and intention for it and updates the beliefs, goto step 3;
- NMA calculates the image strength H1 and H2 of present and previous images, computes $Pth = H1/H2 \times 100$; updates *Pth* to NBB; if ($Pth > Tth$) then *Nstatus* = *Active*, NMA updates the node status and the image to NBB, appends criticalness = 1 to the sensed parameters to generate the belief set; Otherwise *Nstatus* = *Inactive*, NMA agent updates the node status and discards the image, appends criticalness = 0 to the sensed parameters to generate the belief set;
- If NMA makes the decision in favor of critical information, it creates CCIA, CCIA compares the current image with those from the database; if ($HDx,y - HPx,y \leq Tth$), then Context = Emergency otherwise Context = Simple; If (*Context* == *Emergency*), then send message to sink node as emergency context by using flooding mechanism otherwise If(*Context* == *Simple*) send the context information as simple context to the sink and updates SBB;
- If NMA decides in favor of non-critical information then NMA generates NCCIA, provides NC- CIA information about active nodes and location otherwise NCCIA visits all other active nodes and fuses the information;
- stop

END

Sink Agency Algorithm

Nomenclature:F(x,y) = Fused image, N(x,y)= Active node image, *Nactive*= Number of active nodes, i=Index value of the active nodes, (x,y) =Index value of the node image, $N \times N$ = Size of the image.

BEGIN

- SMA gets the context information from SBB; if (*Context* == *Emergency*) then SMA creates FA and provides it with one level wavelet fusion code and the routing information otherwise if (Context==Simple) then it creates FA and provides the two level wavelet fusion code and the routing information;
- FA uses fusion code as per emergency or simple context information and routing information, FA visits active sensor nodes for fusion;
- FA visits active nodes and triggers correlation calculation process and classifies nodes into fusion and non-fusion nodes; FA fuses only from the fusion nodes and then gets back to the sink nodes to convey fused information to the sink;
- FA is disposed;
- Go to Step 1;
- Stop

END

SIMULATION

We have carried out the simulation of the proposed scheme in various network scenarios by using MAT- LAB tool for the performance and effectiveness of the approach. We give details about simulation model and performance parameters considered in simulation.

Simulation Model

Simulation environment comprises of six models namely network model, channel model, propagation model, battery model, context model, and information fusion model. These models are described as follows.

Network model: We considered simulation area of $A \times B$ sq. meters for WSN. A network consists of *num* static nodes that are placed randomly within the given area. Each node has communication radius, *r* mts, and network bandwidth, ***netBW***. ***Fcode*** kbytes wavelet based image fusion code roams around the network.

Channel model: The communication environment is assumed to be contention-free. The transmission of packets is assumed to occur in discrete time. A node receives all packets heading to it during receiving interval unless the sender node is in non-active state. For simplicity, we have considered the channel to be error free. The characteristics of sensor networks and applications motivate a MAC that is different from traditional wireless MACs such as IEEE 802.11 in almost every way: energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. Sensor MAC protocol (S-MAC) uses different techniques to reduce energy consumption and support self-configuration[26]. To reduce energy consumption in listening to an idle channel, nodes periodically sleep. Neighboring nodes form virtual clusters to auto-synchronize on sleep schedules. Simulation environment uses the S-MAC protocol.

Propagation model: Free space propagation model is used with propagation constant β. It is assumed that at any given time, the value of transmitted power is ***NPow*** milliwatts for every node.

Battery model: Image sensor nodes are deployed in the area; recharging of the nodes at the target area is difficult. So, we have considered a solar cell recharging model [27] and a layered clustering model to deal with the restrict energy consumption under the consideration of visual quality. The system lifetime can be prolonged by rechargeable solar cell that can be recharged by solar panel in daytime. Image sensor nodes consumes *node batt* millivolts to sense an image.

Context model: Various contexts considered are - simple context (general object detection context), emergency Context (critical object detection context). The images and their respective contexts are stored in the knowledge base of each sensor. Contexts are randomly generated by assigning a number such that 1 means simple context and 2 means critical object detection.

Information fusion model: Each of the sensor node is associated with battery of *node batt* millivolts. It is assumed that 1 millivolt is decremented for every usage (transmission/processing). *k* number of active nodes are randomly chosen as active nodes from *num* nodes. Set of critical images, present and previous images are stored in the node. Size of the gray images stored at each of the sensor node is fixed.

The fixed gray scale image of size ***rows × columns***, 8 bits/pixel is assigned to each of the active sensor node. *Th*, is the percentage of the threshold image signal strength.

Simulation Procedure

To illustrate some results of the simulation, we have taken *A* = 100, *B* =200 meters, r =1 to 5 mts., *num*= 20 to 100, k = 2 to 80, *node batt*=90 millivolts, Th= 50%, 60 %, 70 %. Gray scale image of varying size: *rows* × *columns*= 32 × 32, 64 × 64, 128 × 128, 256 × 256, with 8, 12, 16, 24 bits/pixel. Present Signal strength= 30%, 50%, 60%, 70%. *netBW* = 4 *MBPS*, propagation Constant β =3.5, and ***Fcode***= 4 and 8 ***Kbytes.***

Simulation procedure is as follows. Generate the WSN for the given radius and number nodes; sense the parameters and generate the active nodes; apply the proposed context aware fusion model; and compute the performance of the system.

Performance parameters considered in the simulation are as follows.

- Node battery usage: It is defined as the battery depleted with the usage of a node.
- Dropping rate: It is defined as the number of packets missed during the transmission of packets, i.e., it is a ratio of packets dropped to packets sent.
- Fusion time: It is the total time required by the FA to fuse the images from active sensor nodes.
- Bandwidth requirement: It is the amount of bandwidth required to transmit the image to sink node, i.e., it is a ratio of image size to available bandwidth.
- Throughput: It is the ratio of number of image packets (data) received to the number of image packets sent.
- Mean square error: It is defined as the standard deviation of the difference image between the ideal and standard image.
- Agent overhead: It is the additional code which acquires the communication channel. It is ratio of image size to sum of agent size and image size.
- Entropy: The entropy of the fused image is given by the equation given below. High value of entropy indicates that the fused image has got good information content in it.

$$Entropy of the fused image = -\sum_{k=0}^{255} (F_k \log_2 F_k) \quad (13)$$

- **Cross Entropy:** Overall cross entropy of the source images, let us say *I*1 and *I*2 are images and the fused image *If* is:

$$CE(I_1, I_2; If) = CE(I_1; If) + CE(I_2; If) \quad (14)$$

Where

Percentage Fit Error:

$$CE(I_1;\ I_f) = \sum_{k=0}^{255} (h_1)\ \log \frac{h_1(k)}{h_f(k)} \quad (15)$$

$$CE(I_2;\ I_f) = \sum_{k=0}^{255} (h_1)\ \log \frac{h_2(k)}{h_f(k)} \quad (16)$$

$$PEF = \frac{norm(I_1 - I_f)}{norm(I_1)} * 100 \quad (17)$$

RESULTS AND DISCUSSIONS

This section presents wavelet transform analysis, fusion time analysis, bandwidth analysis, throughput analysis and node battery usage. Figures 5 and 6 shows the sensed images (we have taken first and last images of the sensor nodes, when there were a total of 12 active nodes) and figure 7 shows the color bar mapped image of the gray scale image. Figures 8 and 9 shows the decomposition and approximation in all directions like vertical, horizontal and diagonal. In the simulation, images shown are taken from fusion process of the last active node. Figure 10 is the fused image and figures 12 and 13 clearly show that the wavelet preserves all spatial information of the image intact. Thus it is advantageous as compared to other fusion techniques.

Figure 5: Sensed Image 1

Figure 6: Sensed Image 2

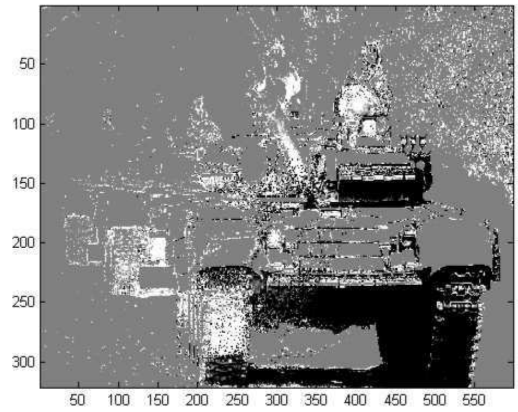

Figure 7: Wavelet Decomposition Image

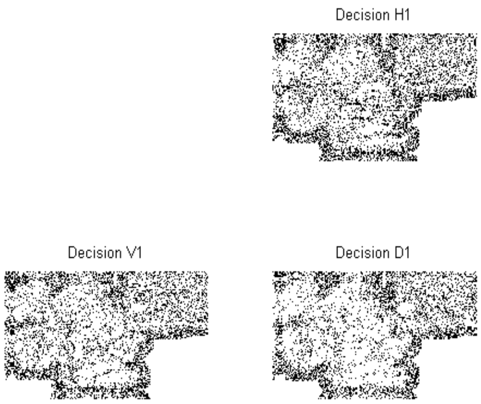

Figure 8: Wavelet Decomposition Level 1

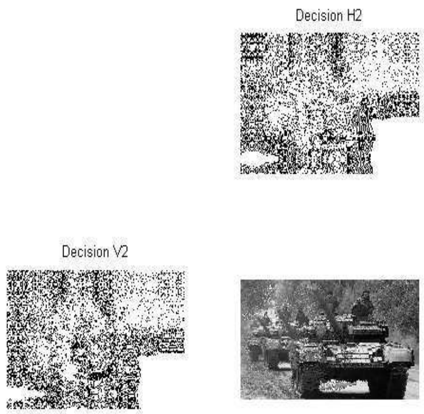

Figure 9: Wavelet Decomposition Level 2

Figure 10: Fused Image

Figure 11 depicts the analysis of fusion time. It shows that as the number of active nodes increase, the fusion time increases, but their is no abrupt increase in the fusion time even if their is increase in number of active nodes. Figure 12 shows that as number of deployed nodes increase along with increase in threshold, number of active nodes decrease and thus fusion time decreases accordingly.

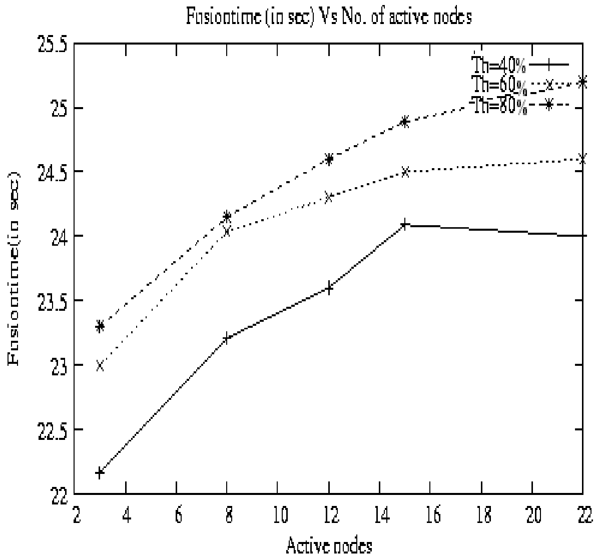

Figure 11: Fusion Time Vs. Active Nodes

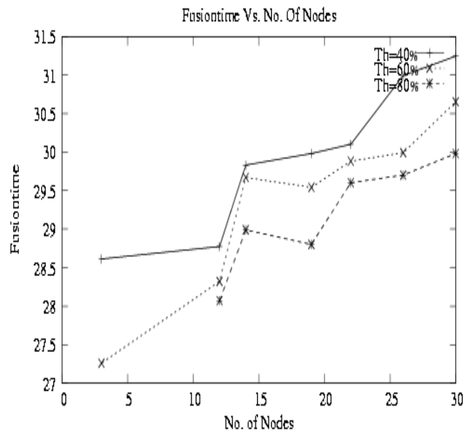

Figure 12: Fusion Time VS. Number Of Nodes

In figure 13, different gray scale images are taken and their used bandwidth against number of active nodes has been analyzed. Bandwidth used increases as there is increase in the number of active nodes for each gray scale image. From figure 14, we can notice that the bandwidth required to transmit increases with increase in the size of the image and threshold of the signal strength.

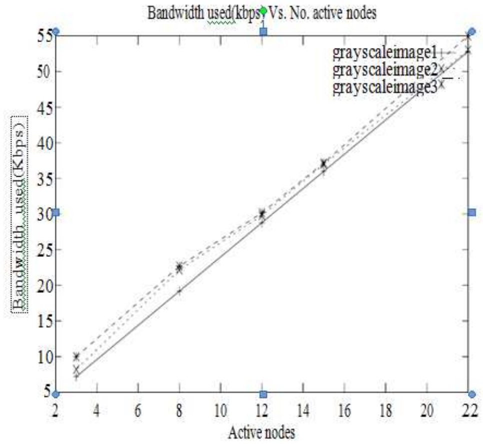

Figure 13: Utilized Bandwidth VS. Active Nodes

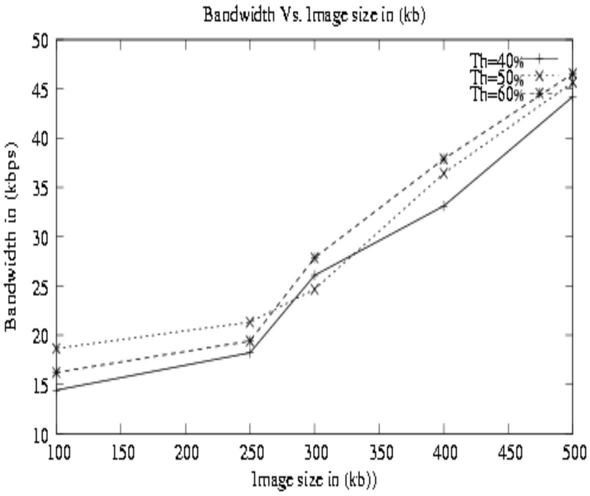

Figure 14: Bandwidth VS. Image Size in (Kb)

Throughput depends on the number of active nodes, as the number of active nodes increase there is a chance of packet loss (we have taken gray scale image). In figure 15, it can be seen that even if the number of active nodes increase, the throughput does not drop drastically. Throughput also depends on number of image packets sent and received. In this analysis, we have considered the gray scale image. While transmitting the image, it is divided into packets and sent. Figure 16 shows that throughput decreases with increase in the image size.

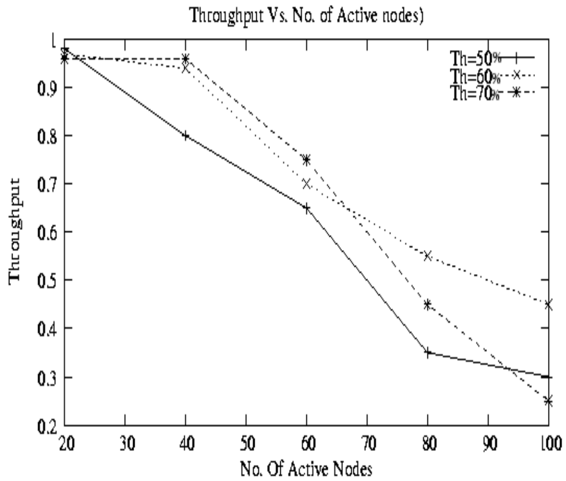

Figure 15: Throughput VS Number of Active Nodes

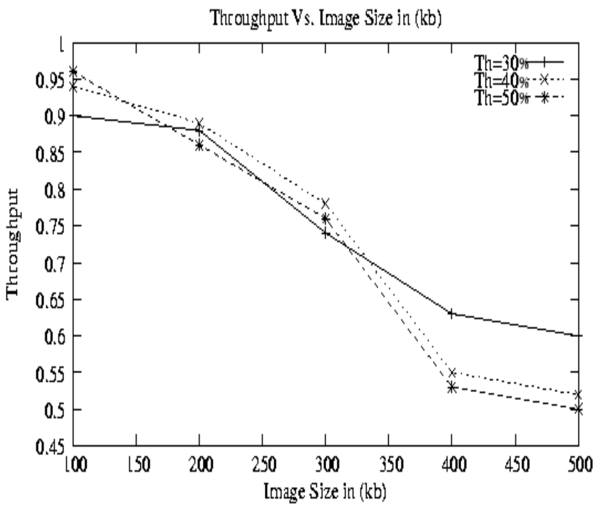

Figure 16: Throughput VS Image Size in (kb)

During the transmission of the image packets in the network, some packets may not reach the sink node. Dropping rate depends on the number of packets dropped. From figure 17, we can notice that dropping rate increases as there is increase in the number of nodes. In figure 18, dropping rate increases with increase in image size. As the size of the image increases, number of packets/image increases. As the threshold is increased, dropping rate reduces.

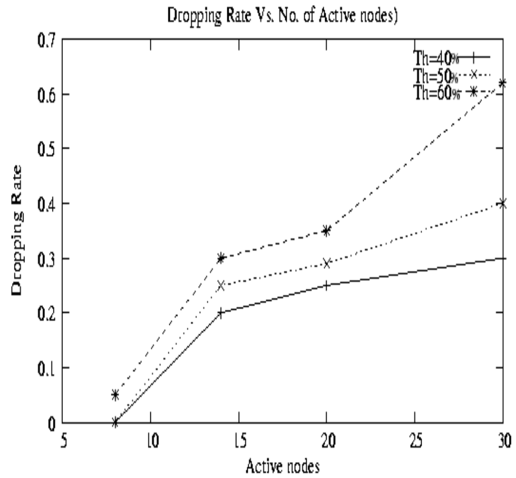

Figure 17: Dropping Rate VS Number of Active Nodes

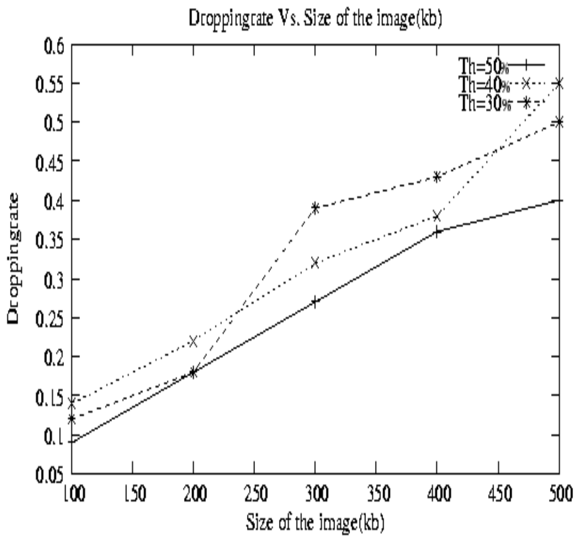

Figure 18: Dropping Rate VS Image Size in (Kb)

The life time of the sensor node mainly depends on the battery life time and its power. Sensor nodes will be active whenever the sensor nodes have the information otherwise nodes status will be inactive (sleep mode). In active mode of the sensor node, sensor nodes consume more power and in inactive mode, nodes consumes less power. This is evaluated by choosing the one sensor node of WSN for repeated simulation. For each of the simulation, sensor node sends the varying number of packets. We observe from the figure 19, that the battery life decreases as the number of packets sent by one of the sensor node increases.

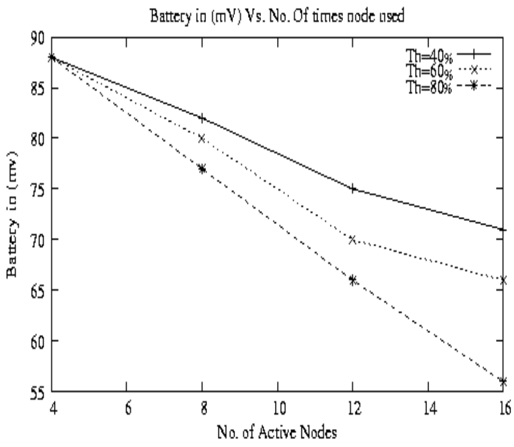

Figure 19: Battery in Millivolts VS. Number of Times Node Used

Now, let us look at some of results with respect to emergency context only. In figure 21, keeping the threshold constant it can be seen that as number of nodes increase despite of different gray scale images being used, the used bandwidth increases. For gray scale image 1, bandwidth used is less as compared to other images. Figure 25 depicts the increase in used bandwidth with the increase in image size. However for higher threshold, bandwidth usage is less.

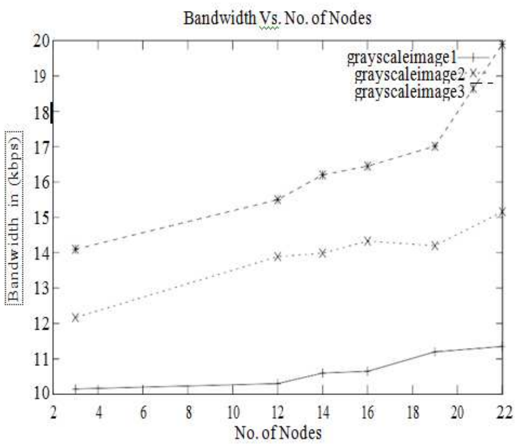

Figure 20: Bandwidth VS. Number of Nodes

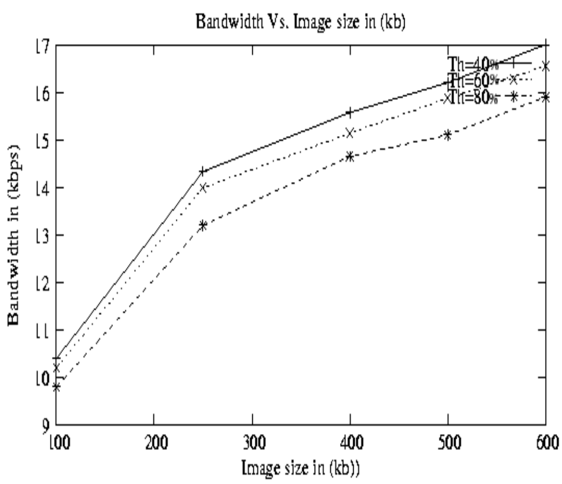

Figure 21: Bandwidth in (kbps) VS. Image size in (kb)

In figure 22, it is observed that as number of nodes increase, fusion time increases. The plot has been given by varying threshold. As the threshold increases, number of active nodes decreases, thus fusion time also decreases.

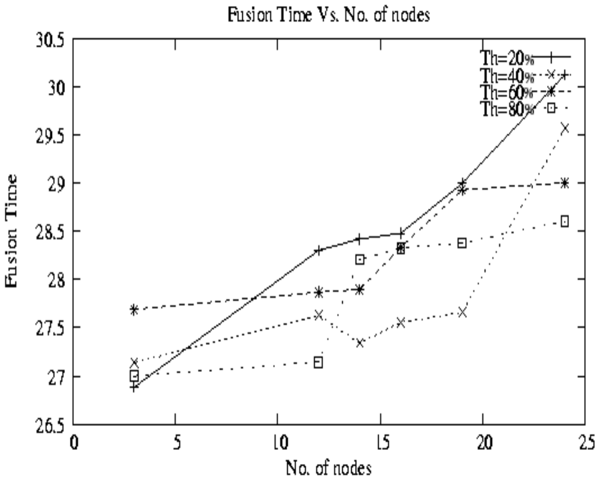

Figure 22: Fusion Time VS. No. of Nodes

Figure 23 gives the plot of the fusion time against active nodes. Here threshold has been varied and it can be observed that as the threshold increases, active nodes decreases, fusion time also decreases. But the increase in the fusion time for each increase in active nodes is at less rate as compared to the plot of fusion time against active nodes for simple context.

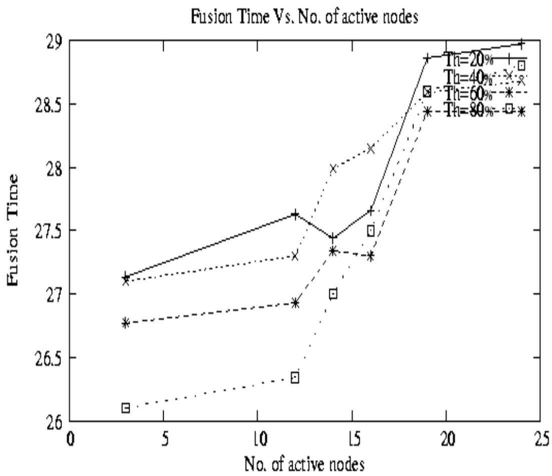

Figure 23: Fusion Time VS. Number of Active Nodes

In Figure 24, the plot of fusion time against number of active nodes has been given. Here the thresh- old has been varied, and as number of active nodes increases, fusion time also increases. As the threshold increases, the number of active nodes decrease and therefore the fusion time will be less.

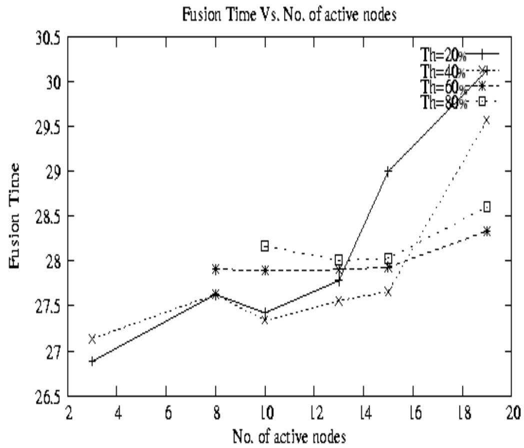

Figure 24: Fusion Time VS. Number of Active Nodes

Comparison between Emergency and Simple Context

Table 2: Comparison between Emergency and Simple Context

Performance Parameters	Emergency Context	Simple Context
Wavelet Decomposition Level	2 Dimensional1 Level	2 Dimensional2 Level
Fusion Time	Less	More
Fused Image Quality	Less Clarity	Good Quality
Bandwidth Utilization	Efficient	Less Efficient
Throughput	Good but depends upon image size	Good but depends upon image size
Dropping Rate	Less	Bit More
Reliability	High	Bit Less
Entropy of fused image	Bit less	High
Cross Entropy ofsensed images and fused images	Very Less	High
Correlation betweensensed image and fused image	Good	Better
Percentage fit error	Less	Very less

Comparison of various performance parameters for Emergency and Simple Context Interpretation The table 2 provides the comparison between the emergency and simple context. Some of the performance parameters are used for comparison, which shows how these parameters behave for each type of context. As depicted earlier, the main concerned of the work is for image fusion. Wavelet has been used for image fusion, basically 1 level decomposition has been used for emergency context and 2 level decomposition has been used for simple context. Various performance parameters mainly like, entropy, cross entropy, Percentage fit error, correlation between sensed image and fused image and absolute mean has been considered for both simple and emergency context and the comparison has been given in the table 2.

CONCLUSIONS

The paper proposed a cognitive agent based context aware image fusion in WSNs to form an infrastruc- ture for image fusion. In an environment where source nodes are close to each other, and considerable redundancy exists in the sensed data, the source nodes generate a large amount of data, which not only wastes the scarce wireless bandwidth, but also consumes a lot of battery energy. Instead of each source node sending sensed images to the sink node, images from the different active nodes are fused and sent to sink node by using a mobile agent. BDI based intelligent agent has been used to interpret the con- text, and the given frame-work can be extended for various sensor input parameters. The use of agents facilitates the following: (1) asynchronous operation, i.e., does not require a continuous connectivity between source and sink, (2) flexibility to change the embedded code to perform context/user driven fusion, (3) adaptability to varying network conditions and the environment for image fusion, (4) ease of maintenance, since the code can be debugged and upgraded independent of other agents in the system, (5) reusing of the code is possible by other applications with slight modifications and put in the system, thus enables dynamic software architecture.

However, there are some issues to be addressed in the proposed scheme, which can be taken up as fur- ther work: security in information fusion by mobile agent, BDI-agent framework supporting persistence and security to agents, tackling the active node failures during fusion process, agent itinerary algorithms, etc.

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