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BDI Agents for Information Fusion in Wireless Sensor Networks

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***Abstract*: Information fusion is one of the major problems in the Wireless Sensor Network (WSN) where data, image, audio, video can be passed through WSN. For efficient usage sensor node energy is one of critical issue of WSN. Using the mobile agents with cognition can prolong the life time of WSN. The conventional agents are not gaining well throughput because they are not too intelligent to act upon the critical conditions like sudden environment change etc, so to overcome from this problem the BDI (Belief Desire Intention) agents are used instead of conventional agents where BDI agents uses their belief, desire and intentions to gather the information from sensor nodes and send within time to the sink node. BDI are autonomous, social ability, reactiveness, proactivity and the special one is intelligence, it uses these characteristic to fuse the information very accurately and send the fused information to the sink node within time. In this paper we describe the usage of agent technology and BDI architectures for information fusion in WSN.**

Index Terms- WSN, Information fusion, Intelligent agents, BDI agents.

I. INTRODUCTION

Wireless sensor networks (WSN) have gained much attention recently [1]. The sensor networks can be used for various application areas such as health, military, environmental monitoring, home, etc. Usually a wireless sensor network (WSN) is composed of a large number of sensor nodes, which are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or pre-determined. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data [2].

A WSN may be designed with different objectives. It may also be designed to monitor an environment for the occurrence of a set of possible events, so that the proper action may be taken whenever necessary. Information fusion arises as a discipline that is concerned with how data gathered by sensors can be processed to increase the relevance of such a mass of data. Information fusion can be defined as the combination of multiple sources to obtain improved information (cheaper, greater quality, or greater relevance). Information fusion is commonly used in detection and classification tasks in different application domains, such as robotics and military applications. Simple aggregation techniques (e.g., maximum, minimum, and average) have been used to reduce the overall data traffic to save energy [3].

Information fusion can be used to compose the complete view from the pieces provided by each node. Redundancy makes the WSN less vulnerable to failure of a single node, and overlapping measurements can be fused to obtain more accurate data. Information fusion can be used to combine complementary data so the resultant data allows inferences that might be not possible to be obtained from the individual measurements (e.g., angle and distance of an imminent threat can be fused to obtain its position).

Agent technologies span a range of specific techniques and algorithms for dealing with interactions with others in dynamic and open environments. These include issues such as balancing reaction and deliberation in individual agent architectures, learning from and about other agents in the environment and user preferences, finding ways to negotiate and cooperate with agents and developing appropriate means of forming and managing coalitions.

BDI stands for (B)eliefs, (D)esires and (I)ntentions, which are mental components present in many agent architectures[15]. In short, belief represents the agent's knowledge, desire represents the agent's goals and intention lends deliberation to the agent. The exact definition of these components will vary from author to author. One can expect to see different interpretations of these mental components in different applications. Further sections are II) Information fusion WSN, III) Agent technology, IV) BDI agents, V) BDI Agents for Information Fusion in WSN, VI) related work and lastly Conclusion.

II. INFORMATION FUSION IN WIRELESS SENSOR NETWORK

WSNs are deployed in environments where sensors can be exposed to conditions that might interfere with the sensor readings or even destroy the sensor nodes. As a result, sensor measurements may be more imprecise than expected, and the sensing coverage may be reduced. A natural solution to overcome failures and imprecise measurements is to use redundant nodes that cooperate with each other to monitor the environment. However, redundancy poses scalability problems caused by potential packet collisions and transmissions of redundant data. To overcome such a problem, information fusion is frequently used. Briefly, information fusion comprises theories, algorithms, and tools used to process several sources of information generating an output

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that is, in some sense, better than the individual sources. The proper meaning of "better" depends on the application. For WSNs, "better" has at least two meanings: cheaper and more accurate [4].

Information fusion can be categorized based on several aspects. Relationships among the input data may be used to segregate information fusion into classes (e.g. cooperative, redundant, and complementary data). Also, the abstraction level of the manipulated data during the fusion process (measurement, signal, feature, decision) can be used to distinguish among fusion processes. Another common classification consists in making explicit the abstraction level of the input and output of a fusion process.
Common classifications of information fusion are explored in this section.

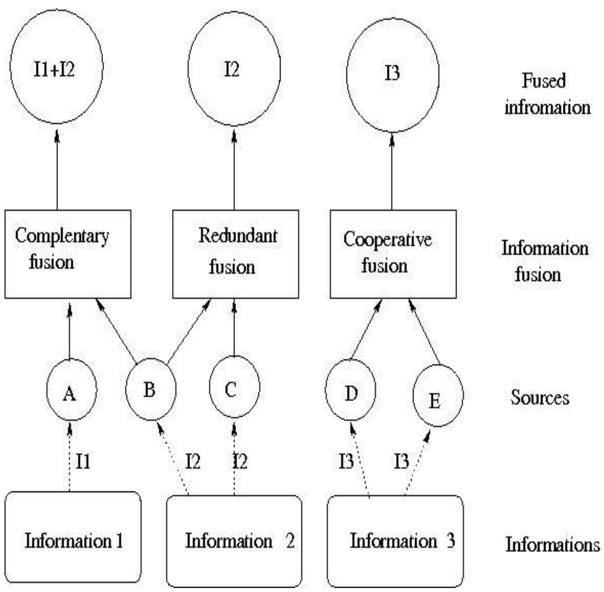

Fig1: Information fusion in WSN

Types of information fusion based on the relationship among the sources, figure1 adapted from [10] where Complementary is used When information provided by the sources represents different portions of a broader scene, information fusion can be applied to obtain a piece of information that is more complete (broader). Redundant: If two or more independent sources provide the same piece of information, these pieces can be fused to increase the associated and Cooperative: Two independent sources are cooperative when the information provided by them is fused into new information (usually more complex than the original data) that, from the application perspective, better represents the reality [4].

III. AGENT TECHNOLOGY

Agents can be defined to be autonomous, problem-solving computational entities capable of effective operation in dynamic and open environments. Agents are often deployed in environments in which they interact and maybe cooperate with other agents (including both people and software) that have possibly conflicting aims. Such environments are known as Multiagent systems. The use of agent systems to simulate real-world domains may provide answers to complex physical or social problems which would be otherwise unobtainable, as in the modeling of the impacts of climate change on various biological populations, or modeling the impact of public policy options on social or economic behavior.

An intelligent software agent is a computational process which has several characteristics: [17]"reactivity" (allowing agents to perceive and respond to a changing environment), [18]"social ability" (by which agents interact with other agents) and [19]"Proactiveness" (through which agents behave in a goal-directed way).

Agents can be distinguished from objects (in the sense of object oriented software) in that they are autonomous entities capable of exercising choice over their actions and interactions. Agents cannot, therefore, be directly invoked like objects. However, they may be constructed using object technology. Agents can be written in Java, Tcl, Perl and XML languages [1]. An agent interpreter depends on the type of agent script/language used. An agent platform offers the following services: creation of static and mobile agents, transport for mobile agents, security, communication messaging and persistence.
Agents may be static or mobile. In this section we describe the mobile and static agent.

(a)Mobile agents:

A mobile agent is a composition of computer software and data which is able to migrate (move) from one computer to another autonomously and continue its execution on the destination computer. A Mobile Agent, namely, is a type of software agent, with the feature of autonomy, social ability, learning, and most importantly, mobility. More specifically, a mobile agent is a process that can transport its state from one environment to another, with its data intact, and be capable of performing appropriately in the new environment. Mobile agents decide when and where to move. Movement is often evolved from RPC methods. Just as a user directs an Internet browser to "visit" a website (the browser merely downloads a copy of the site or one version of it in the case of dynamic web sites), similarly, a mobile agent accomplishes a move through data duplication. When a mobile agent decides to move, it saves its own state, transports this saved state to the new host, and resumes execution from the saved state.

(b) Static agents:

A Static (stationary) agent executes only on the system where it begins execution. If it needs information that is not on that system, or needs to interact with an agent on a different system, it typically uses a communication mechanism such as remote procedure calling (RPC).

Three different types of agents which are used in the fusion process are follows

1) Surveillance-sensor agent: This type of agent tracks all the objects and sends the data to a fusion agent. It acquires the environment information through a camera and performs the local signal processing side. The tasks carried out are: detection of objects, data association, state estimation, projection on fusion coordinates and the communication with the fusion agent.
2) Fusion agent: It performs the fusion of the data received from each surveillance agent. Then they fuse the information received from the surveillance-sensor agents, which is received in FIPA ACL messages and it is time stamped.
3) Interface agent: This agent receives the fused data and shows it to the final user. It is also the user interface of the surveillance application.

(b)Agent based information fusion:

In this section, we describe the agents information fusion using agents, Agents are employed [6] in peer-to-peer sensor networks to perform data fusion for supporting situation awareness on the digital battlefield. The work given in [7] is based on applying mobile agents for wireless sensor networks that collects the data and sends to sink. Here the fusion agent receives tracks information from the sensor agents through a TCP/IP network using FIPA ACL [5] messages performs the fusion of the data received. The most important fusion agent parameters involved in the fusion process are:

IV. BDI AGENTS

The Belief-Desire-Intention (BDI) software model is a software model developed for programming intelligent agent superficially characterized by the implementation of an agent's beliefs, desires and intentions, it actually uses these concepts to solve a particular problem in agent programming. In essence, it provides a mechanism for separating the activity of selecting a plan (from a plan library) from the execution of currently active plans. Consequently, BDI agents are able to balance the time spent on deliberating about plans (choosing what to do) and executing those plans (doing it). A third activity, creating the plans in the first place (planning), is not within the scope of the model, and is left to the system designer and programmer. The Belief-Desire-Intention (BDI) model has been proved as a dominant view in contemporary philosophy of human mind and action. We utilize BDI as a tool to analyze agent's environments, goals, and behaviors. In BDI agents the meaning of BDI represents as follows.

Beliefs: Beliefs represent the informational state of the agent, in other words its beliefs about the world (including it and other agents). Beliefs can also include inference rules allowing forward chaining to lead to new beliefs. Using the term belief rather than knowledge recognizes that what an agent believes may not necessarily be true (and in fact may change in the future).

Desires: Desires represent the motivational state of the agent. They represent objectives or situations that the agent would like to accomplish or bring about. Examples of desires might be: find the best price, go to the party or become rich. Goals: A goal is a desire that has been adopted for active pursuit by the agent. Usage of the term goals adds the further restriction that the set of active desires must be consistent.

Intentions: Intentions represent the deliberative state of the agent - what the agent has chosen to do. Intentions are desires to which the agent has to some extent committed. In implemented systems, this means the agent has begun executing a plan. Plans: Plans are sequences of actions that an agent can perform to achieve one or more of its intentions. Plans may include other plans: my plan to play cricket and to score good runs may also include plan to find good wicket to bat on.
The figure 2 shows general BDI architecture, it shows how BDI works when it get information from sensor node.
The knowledge box is needed and is used by mobile agent to decide which route to be selected next. Static agent constructs and maintains the interest cache, other static agent's energy models, self model and forwarding table (Routing Table).

General BDI architecture:

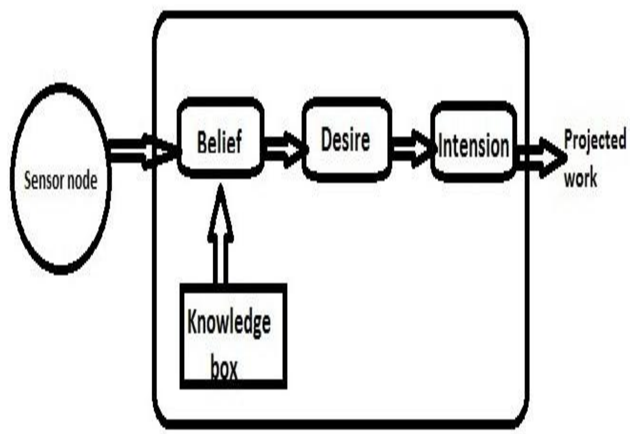

Fig2: General BDI agent Architecture

V. BDI AGENTS FOR INFORMATION FUSION IN WSN

A. System Environment:

BDI Agent based information fusion is represented in below shown figure3, where all the nodes are randomly deployed and if an event occurs in the environment means more than one node has that information so to make information fusion BDI agent is generated at the node, all the nodes have a capability to generate BDI agent. Now BDI agent will migrate from one node to another fuse the entire event occurred information and also gets information about the neighbour nodes and updates its knowledge box, and now BDI agent move to next event accoured node and continue its fusing process. While routing the information from event

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occurred nodes to the Sink Node (SN) it uses intermediate nodes as it consumes some energy. On routing if the intermediate node is dead or the environmental condition is not suitable to route means the BDI agent changes its path and select the suitable path to route the information this shows intelligence of the BDI agent as shown in below shown figure3.

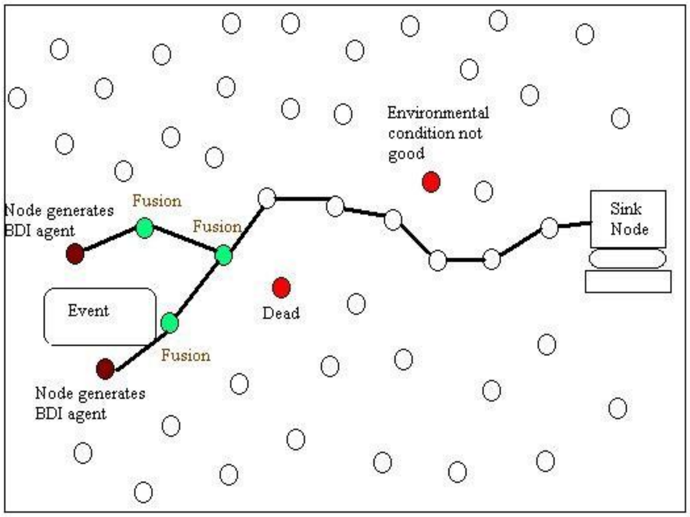

Fig3: Information fusion in WSN using BDI agent

VI. RELATED WORKS:

(A) Fuzzy Decision Making through Energy-aware and Utility Agents within Wireless Sensor Networks:

This paper proposed that the Multi-agent Systems (MAS) through their intrinsically distributed nature offer a promising software modeling and implementation framework for Wireless Sensor Network (WSN) applications. WSNs are characterized by limited resources from a computational and energy perspective; in addition, the integrity of the WSN coverage area may be compromised over the duration of the network's operational lifetime, as environmental effects amongst others take their toll. Thus a significant problem arises and the agent can't construct an accurate model of the prevailing situation in order that it can make effective decisions about future courses of action within these constraints so that BDI architecture is used. The BDI model represents an abstraction of human deliberation and is based on a theory of rational activity in the human cognition process. In particular, the fundamental issue of belief generation within WSN constraints using classical reasoning augmented with a fuzzy component in a hybrid fashion is explored in terms of energy-awareness and utility.

Energy-aware and utility-based agents [8] have been proposed to provide solutions to the modeling of distributed intelligence modeling for resource-bounded sensors. The authors view the matured BDI paradigm as an effective solution to such pervasive issues as load balancing, routing and distributed data processing.

In this paper a two-level BDI multi-agent system is proposed the higher-level MAS consist of a number of WSN subsets. This MAS is comprised of resource-rich members, and may be regarded as constituting a classic BDI MAS. Within these MAS, information may be freely exchanged without regard to cost constraints. Indeed, decisions that affect the entire network may be made at this level. The beliefs that inform these decisions are those propagated from the lower-level MAS, that is, the individual sensors, via their BSs.

Belief Generation in a Fuzzy Context:

While data gathering is a general term for collecting data from multiple sensors, the terms data aggregation and data fusion both refer to the analysis and interpretation of the data. Though these terms are commonly used, there is not a complete consensus as to their meaning [9]. Thus, as far as this discussion is concerned, data aggregation, data gathering and data fusion all refer to the combination of multiple sensor data into one representation or control action. When BDI agents are considered in a WSN context, it can be seen that in generating their beliefs, a BDI agent is essentially engaging in an exercise of data fusion or data aggregation.

A prerequisite to the successful deployment of agents within WSNs is a capability to reason in a distributed manner and with partial, noisy and incomplete knowledge. In the case of BDI agents, this has implications for the belief generation process.

In brief the author has tried to describe the design and operation of energy-aware and utility-based agents. They have focused in particular upon the core issue of belief generation within computationally challenged environments. It has outlined experimental work and initial results that support the efficacy of the proposed approach. Energy-aware utility-based agents offer a hybrid approach to deliberative reasoning by combining fuzzy reasoning with classical BDI approaches.

(B)Information Fusion for Visual Reference Resolution in Dynamic Situated Dialogue

Human-Robot Interaction (HRI) invariably involves dialogue about objects in the environment in which the agents are situated. The paper focuses on the issue of resolving discourse references to such visual objects. The paper addresses the problem using strategies for intra-modal fusion and inter-modal fusion .Where Inter-modal fusion relates the use of object references across different modalities, e.g. the resolution of an exospheric linguistic reference against an object in the robots perceptual field .Within the framework and Inter-modal fusion results in the binding of equivalence classes from different modalities. A key element of the inter-modal fusion process is the use of ontology-based mediation to provide a mapping between conceptual systems to establish whether we can relate percepts from different modalities. Core to these strategies are sensorimotoric coordination, and ontology-based mediation between content in different modalities. One of the main advantages of this framework is that it provides a mechanism for dealing with the temporal dimension of situated reference. The approach has been fully implemented, and is illustrated with several working examples [11].

The BDI based process used as a mediate between different subsystems. In this belief provides a common ground between different modalities, rather than being a layer on top of the different modalities. Beliefs thus provide a means for cross-modal information fusion, in its minimal form by co-indexing references to information in individual modalities [12]. The author has used bounding box-method to determine the region of interest in the image for that SIFT-based model should be learned. Create a visual referent id for the resulting model, and store this id in a new visual EC for the object. We provide the EC with a structural description of the object ("box") based on what was said [13]. Then return the identifiers of the sighting and its visual EC to BDI mediation. BDI mediation creates a belief in which the dialogue and visual ECs are connected, and informs the communication subsystem that a visual model has been successfully acquired for the robot to provide feedback.

(C) Extending BDI Multi-Agent Systems with Situation Management:

In this [14] author explained about extension of BDI (Belief, Desire, and Intention) agent model by enabling agent beliefs to be based on real-time situations that are generated by a Situation Management (SM) system. Situation management is intended for application domains characterized by large volumes of real-time events and complex domain models which require a combination of data fusion, event correlation and semantic reasoning in order to identify and assess the current context and recommend actions. SM system has several advantages for multi-agent systems using BDI agents. 1) Because of the use of event correlation and data fusion techniques in situation management, agent platforms can support highly reactive distributed applications. 2) The situation manager provides a semantically rich representation of the world and can dynamically adapt its representation for situations over time. BDI agent model is a well-established approach to designing deliberative agent systems. Extend the BDI (Belief, Desire, and Intention) agent model by including agent beliefs that are real-time complex situations generated by a situation management system. This integration produces SBBDI (Situation-Based BDI) agents which can support highly reactive applications and an enhanced representation of agent beliefs.

There are several future research issues of SBBDI agents that need to be addressed:

a. Effective situation specification languages and methods that preserve the completeness and correctness of situations.

b. Synergistic two-way communication between the basic BDI agent model functions and the situation management functions to increase the overall effectiveness of the SBBDI agent.

c. Learning situations by the SBBDI agent system.

(D) Multi-Agents Supporting Reflection in a Middleware for Mission-Driven Heterogeneous Sensor Networks

This paper presents the concepts of a middleware needed to address mission-driven heterogeneous sensor networks deployed in highly dynamic scenarios [16]. The emerging applications using sensor networks technologies constitute a new trend requiring several different devices to work together and this partly autonomously. However, the integration and coordination of heterogeneous sensors in these emerging systems is still a challenge, especially when the target application scenario is susceptible to constant changes. Such systems must adapt themselves in order to fulfill requirements that can also change during the system runtime. The reflective behavior must be provided for quick decision. This paper presents a reflective middleware that supports reflective behaviors to address adaptation needs of heterogeneous sensor networks deployed in dynamic scenarios. This middleware presents specific handling of users' requirements by representing them as missions that the network must accomplish with. These missions are then translated to network parameters and distributed over the network by means of the reasoning about network nodes capabilities and environment conditions. A multiagent approach is proposed to perform this initial reasoning as well as the adaptations needed during the system runtime. Here BDI approach is used for network wide reasoning. The overall adaptation from this paper is that inclusion of the agent's concepts in the simulator framework, and an interface with the Mission Specification Console.

(a) Planning-Agent model:

The author used different types of agents like cognitive and reactive in order to perform different activities in the middleware, from the provisioning of simple services to complex reasoning about the network setup but given more stress on cognitive agents. The model used in the present approach for the cognitive agents is based on the model of mental attitudes, known as BDI model (Believes-Desires-Intentions). The BDI approach appears to suite well to the problem addressed in this work, as some decisions that must be taken by the agents in the proposed approach require cognitive skills to "wonder" if certain actions are adequate to achieve a desired result, based on knowledge about conditions that may interfere on the performance of those actions. The BDI model presented in this paper has given more focus on sensor networks activities, in which the network nodes do not perform any action that changes the world around them, what simplifies the model by eliminating the assumptions about this aspect. The proposal herein is simpler.

(b) Architectural Structure:

Cognitive planning-agents architecture has been described in this paper based on the BDI architecture which is shown as below figure4.

The author also described Stepwise description about the architecture like how BDI updates its belief according to the current intentions and how it considers the new plans to achieve its goal, the architecture also explains option generator, planning agent and filters etc. then author moved towards multi agent reasoning in that mapping function is explained with stepwise.

(E) Analysis of Distributed Fusion Alternatives in Coordinated Vision Agents:

In this paper [20], details some technical alternatives when building a coherent distributed visual sensor network by using the Multi-Agent paradigm. The Multi-Agent paradigm fits well within the visual sensor network architecture and one of the main advantages using a visual sensor networks is the increase of spatial coverage. In order to have a global view of the environment under surveillance the visual sensors must be correctly deployed. . In this paper they specially focus on the problem of distributed data fusion. Three different data fusion coordination schemes are proposed and experimental results of Passive Fusion are presented and discussed. The main contributions of this paper are twofold, first one is propose the use of Multi-Agent paradigm as the visual sensor architecture and present a real system results. Secondly, the use of feedback information in the visual sensors, called Active Fusion, is proposed. The experimental results prove that the Multi-Agent paradigm fits well within the visual sensor network and provide a novel mechanism to develop a real visual sensor network system. Many Multi-Agent languages and frameworks have been developed. The proposed architecture is based on the open source framework Jadex. Jadex is a Belief-Desire-Intention (BDI) Multi- Agent model. The BDI model provides a way to conceptualize the system and structure its design.

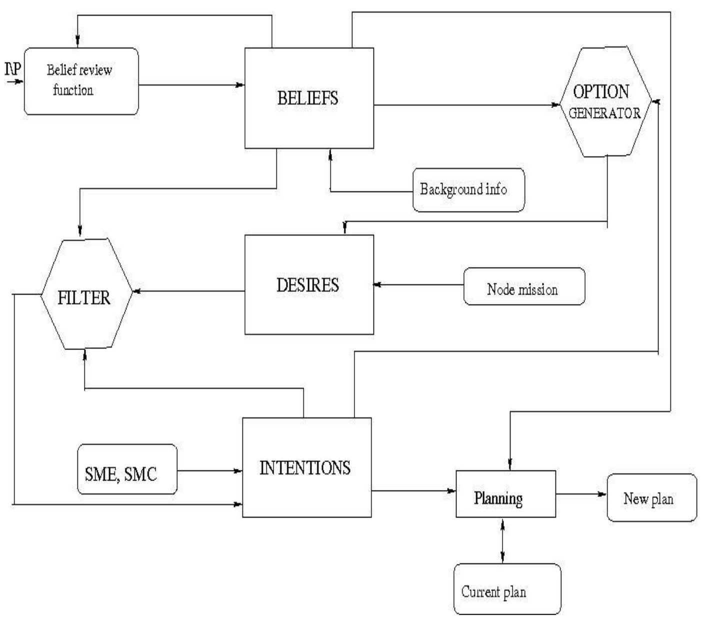

Fig4: Planning-agent Internal Architectural Structure.

Types of fusion considered are Passive fusion (sends the tracks of information to the fusion agent), Active fusion (in this fusion process deals with data incest) and Peer to Peer fusion (the fusion is performed inside each surveillance-sensor agent and then it is sent to the fusion agent).

The author has given a brief explanation about passive fusion by showing a simple experiment where in that he made two conditions first one is normal condition, in normal condition he took three surveillance-sensor agents and one fusion agent. Each surveillance-sensor captures the events happening in the room and collects the information every time and sends the collected information to the fusion agents. The second one is abnormal condition, if the error occurs in any one of the sensor agent means the fusion agents can't accept the information from that sensor agents from that it concludes that some changes has occurred in that particular area send that information to the sink node.

VII CONCLUSION

The BDI agents use its belief desire intension technique in agent technology to overcome the problems occurred by using simple agent technology in wireless sensor networking where the numbers of distributed systems present in it. Problems like, the agent may not be able to react to circumstance change in time and in certain conditions like, agent need more execution time than a time slice, can never be executed. The BDI agents also have database in them, where it can store data in it and uses whenever it is required. BDI software model (in terms of its research relevance) is the existence of logical models through which it is possible to define and reason about BDI agents. BDI Agents are used in case of fusion because it has natural abilities of doing several things at the same time and the BDI agent is able to deliberate on some new beliefs to plan for future actions while executing an existing intention; the agent is able to execute several intentions at once

These all characteristics of BDI agent leads to improve the fusion process in the wireless sensor network because WSN facing major problem for information fusion. We have seen how BDI agents works in WSN for fusing the similar information by taking some related works and some examples.

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