Virtual Medical Board: A Distributed Bayesian Agent Based Approach

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***Abstract*—Distributed Decision Making has become of increasing importance to get solution of different real life problems, where decision makers are in geographically dispersed locations. Application of agent and multi agent system in this Distributed Decision Support System is an evolving paradigm. One of such real life problem is medical diagnosis. For critical medical diagnosis, medical board is formed which is a coordinative discussion mechanism between a group of expert physicians to diagnose a patient. But always forming a medical board with a group of expert physicians may not be possible due to lack of infrastructure, availability, time etc. In that situation the role of multi agent based distributed decision making can comes into play. In this paper we develop a Virtual Medical Board System in which a number of software agents(expert agents) act as a group of expert physician with knowledge base(KB), reasoning capability. They coordinatively discuss with each other to diagnose a patient. We represent the discussion module of the system in the form of Bayesian Network of Bayesian Agent(BNBA). In BNBA each BA is the expert software agent whose Knowledge Base(KB) is represented in the form of Bayesian Network(BN). Also the BDI(Belief,Desire, Intention) model of each BA is represented in this paper.**

***Index Terms*—Vitual Medical Board, Bayesian Network Of Bayesian Agent, Multi agent system, Expert agents, Coordination ontology, Distributed decision support system, BDI architecture.**

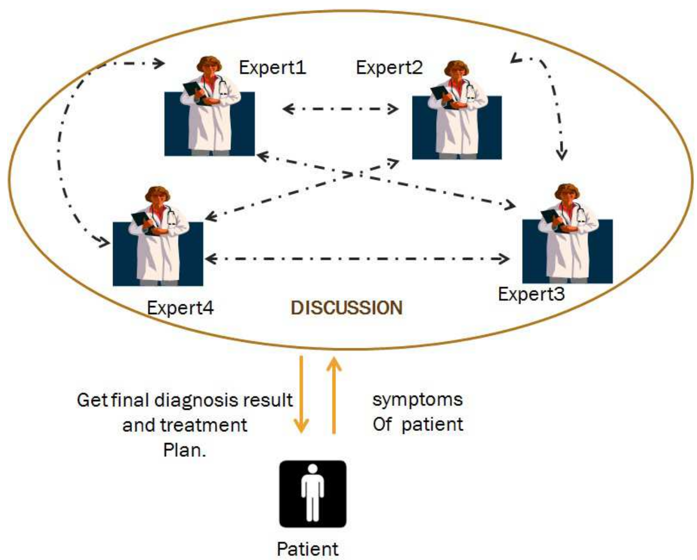

Fig. 1: Brief architecture of the traditional medical board system

I. Introduction

Proper medical treatment starts with proper medical diagnosis. Accordingly, doctors are trained to look for certain medical conditions when specific symptoms are presented by patients. When those symptoms are missed and a condition goes undiagnosed, the potential consequences can be fatal. While diagnosing a patient, sometimes it happens that the doctor is not able to reach any final conclusion regarding the disease and its treatment plan by himself, then he may need to consult with his fellow colleagues or some expert in that field. The group formed by those expert physicians is called Medical Board. Members of Medical Board coordinatively discuss with each other to diagnose a patient properly. Figure 1 shows the broad architecture of conventional medical board system.

Medical board formation is costly method and it need a developed infrastructure in the hospital. For that it is impossible to form medical Board to diagnose a patient in rural side hospital having weak infrastructure. Where very few number of unexperienced quake doctors are light of hope, there getting a group of expert physicians is beyond of imagination. For this a number of poor people die every year due to lack of proper diagnosis and treatment. So to provide rural side common people a sophisticated medical facility like medical board, virtual medical board can be formed.

An agent [1] , [2] is a computer system or software that can act autonomously in any environment, makes its own decisions about what activities to do, when to do, what type of information should be communicated and to whom, and how to assimilate the information received. Multi-agent systems (MAS) [1] , [2] are computational systems in which two or more agents interact or work together to perform a set of tasks or to satisfy a set of goals.

Multi agent system(MAS) based decision support system [3] is a system where number of software agents take a decision of a given problem collaboratively. That is here each agent plays role of a human entity in human-based group discussion methodology. Like human based discussion method each agent communicate with each other i.e. share their opinions or decisions regarding to a given problem for its solution. This communication is based on an agreed common vocabulary with explicit semantics so that all the agents can communicate in the same terms. We define this common vocabulary as coordination ontology which contains set of rules by maintaining them agents can coordinate with each other to negotiate in a final decision successfully.

Multi agent based distributed decision support system is the key idea in forming virtual medical board. Here number of software agents act as group of expert physicians forming medical board. As in medical board each expert physician has medical knowledge based on which he can take a decision in order to diagnose the patient properly, in Virtual Medical Board system each software expert agent has a medical knowledge base depending on which it can diagnose a patient. In our system we represent the knowledge base of expert agent in the form of Bayesian network.

A Bayesian network or Bayes network or belief network or Bayes(ian) model or probabilistic directed acyclic graphical model [4] is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph (DAG). As medical diagnosis is a probabilistic method so in our system we use Bayesian network to represent the knowledge base of each expert agent by specifing probabilistic relationships between diseases and symptoms. Given symptoms, the network can be used to compute the probabilities of the presence of various diseases.

Ontology [5] is the most suitable representation of domain knowledge because concepts, relationships and their categorizations in a real world can be represented with them. With the concept of Ontology we can say that coordination ontology is the domain specific ontology which contains some rules and methodologies about how to take a ultimate decision by a number of decision maker by resolving different obstacles during group discussion.

The rest of the paper is organized as follows. First, Section 2 reviews some related works. In section 3 scope of the work is discussed. Then, Section 4 describes the system model, in which 4.1, 4.2, 4.3 and 4.4 we describe system architecture, Algorithm to form Conditional probability table of 'Final'variable, Architecture of BNBA or discussion module and BDI architecture of each BA respectively. Section 5 presents a case study and result discussion. In section 6 we discuss the problem formulation. Finally, Section 7 presents our conclusions and future work.

II. Related Work

There have been a significant number of contributions in the area of agent oriented decision support system in Medical diagnosis. In [6] authors discuss an agent based coordination mechanism for medical collaborative diagnosis. Here a set of software agents coordinatively diagnose a patient with the help of medical knowledge base and Patient's medical past history. Different agent plays different roles(Manager agent,Distributer agent, Data agent, planning agent etc) in order to get diagnosis result. But each of them follows a single Medical Knowledge base to diagnose the patient. So it is a centralized-knowledge-base approach as diagnosis result depends on only one medical knowledge base which is a bottleneack to get correct diagnosis result. In [7] authors propose an intelligent multi agent system, named IMASC for assisting physicians in their decision making tasks. Here also no group discussion mechanism is presented to achieve correctness in decision as dignosis is based on single medical database. In [8] authors propose networked multi agent system. In networked multi agent system, the interaction structures can be shaped into the form of networks where each agent occupies a position that is determined by such agent's relations with other agents. To avoid collisions between agents, the decision of each agent's strategies should match its own interaction position. So to solve a critical problem different agent takes different strategies according to their position in network. Here it is not shown if two agents take same strategies to solve a problem how to make the solution. In [9] authors have proposed a Bayesian Network (BN) based decision making system which has been designed on the domain of pediatrician. An agent called Intelligent Pediatric agent (IPA) is imitating the behavior of a pediatrician. IPA is single diagnostic agent responsible for diagnosing the patient to take decision that to which specialist the patient should be sent. But here no group discussion methodology among number of number of IPA about their decision is defined. In paper [10] authors present a child patient diagnosis mechanism where a Intelligent Pediatric Agent(IPA) maintain medical knowledge base in the form of bayesian network. From child patient when set of symptoms are taken then Bayesian Network based engine diagnose the disease and send the diagnosis result to user agent (UA). Here also diagnosis depends only the knowledge base of Intelligent Pediatric Agent(IPA) but no discussion procedure among physicians is proposed. So correctness or availability of diagnosis is guaranteed in this system. In paper [11] authors propose a method to convert medical database named as Nautilus into ontology. A tool virtual-stuff is formed which enable a cooperative diagnosis by some of the health care network actors, by relying on this medical ontology and on the creation of SOAP and QOC graphs. But in the proposed diagnosis method group discussion is absent. In [12] , [13] distributed decision making for partially observable environment is proposed. Here each node partially observe the environment. So each agent has their own different goal. When each node achieves their own goal, collaboratively main goal get achieved. But here it is not shown how agents collaboratively take a decision to achieve a same goal. In paper [14] medical disgnosis based on semantically distributed knowledge base is defined. In this paper a number of physician from different medical field perticipate in diagnosis. Main problem is devided into number of subproblems and each physician deals with different subproblems. It is assumed here that there is no conflict between each physicians decision. But here also it is not shown how number of physicians deals with same problem and how to resolve conflictness between their decision. In [15] probabilistic reasoning in distributed decision support system is proposed. Here decsion is taken by number of agents using conditional probabilistic values. Here also lack of group discussion mechanism is present.

III. Scope of Work

There have been a lot of contribution in the area of agent based decision support system in Medical Diagnosis. But most of them are centralized-knowledge based or single diagnostic agent based in nature. That is depending on single medical ontology of a diagnostic agent diagnosis of a patient is done. There is no human oriented medical board like group discussion mechanism to diagnose a patient. Some of the papers are on distributed decision support system. But here a main problem is divided into number of subproblem, where each agent deals with different subpart of main problem. But it is not proposed that how to take a final decision if number of agents are dealing with a same problem. In our work we propose a system which is virtualization of medical board. Here number of software agents with knowledge base act as a group of expert physician. Where each physician handles same patient with same symptoms, dianoses the patient independently, take diagnosis decision, communicate with each other to share their decisions. Finally ultimate diagnosis decision is taken with the help of coordination Ontology.

IV. System model

A. System Architecture

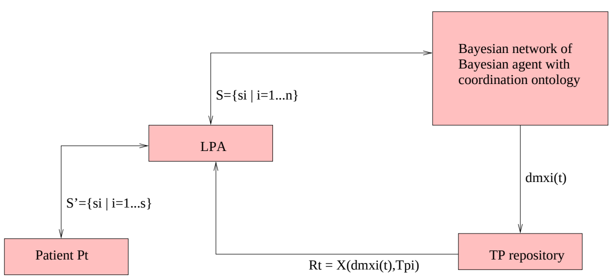

Fig. 2: Brief architecture of the proposed System

Figure 2 represents the brief architecture of our proposed system. Here S' is the set of symptoms of patient P_t. LPA adds some signs in the set S', and new set S is the set of sign and symptoms of that patient, so $n \geq s$. LPA sends this set S to the discussion module of the system. We represent it by 'Bayesian network of Bayesian agent with coordination ontology'. From the module final diagnosis result $dmx_i(t)$ is chosen which is send to Treatment plan repository. From which corresponding treatment plan Tp_i is chosen and report $R(t)$ is generated. Report $R(t)$ is send back to LPA. Figure 3 represents system architecture with detail architecture of discussion module . Formally system architecture can be defined by a set of touple,

VBMS = $\{HA, BNBA, CO, Tprep\}$

where

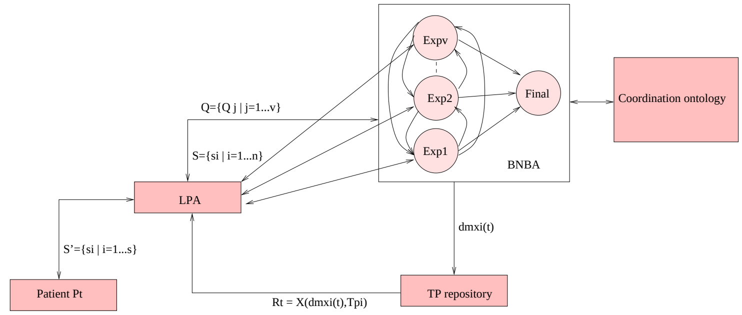

Fig. 3: Detail architecture of the proposed System

- HA : Human agent. There are two types of human agent. 1. Patient 2. Local physician Agent(LPA)
- $BNBA$: Bayesian network of Bayesian Agent(BNBA) is part of discussion module of the system. It is a graph which can be represented by a set of touple, $BNBA = \{V, E, P\}$ where,
  - V is set of variables in the BNBA which act as nodes in graph. Two types of variables are there, 1.NV: Normal variable having number of mutual exclusive states.
    2.BAV: In the system each software expert agent also can be denoted as Bayesian Agent variable having number of mutual exclusive states. These variables or expert agents are called Bayesian Agent variable because each variable itself consists a knowledge base(KB) which is in the form of Bayesian Network. So Bayesian network of each Bayesian Agent can be represented by a set of touple, $BN = \{V', E', P'\}$ where,
    * V' : Set of variables in the Bayesian Network of each Bayesian Agent which act as nodes of the graph. In our application there are two type of variables, 1. Ds: Set of disease variables.
      2. Sy: Set of symptom variables.
      so we can say, $V' = (Ds \bigcup Sy)$
    * E' : Set of directed edges which represents the causal relationships between variable V'.
    * P' : Joint probability distribution over variable V'. It is defined as,
      $P(V'_1, V'_2....V'_w) = \Pi_{i=1}^{w}\ p(V'_i|\text{parents}(V'_i))$
  - E: Set of directed edges which represent causal relationships between variables V.
  - P: Joint probability distribution over variable V. It is defined as,
    $P(V_1, V_2....V_x) = \Pi_{i=1}^{x}\ p(V_i|\text{parents}(V_i))$
- CO: Coordination Ontology is a part of discussion module. It contains set of rules which are used to get final decision among a number of alternative decisions. It is represented by a set of touple $CO = \{C, I, RL\}$ Where,
  $C \rightarrow$ set of classes.
  $I \rightarrow$ set of instances of classes.
  $RL \rightarrow$ set of relationships defined between classes.

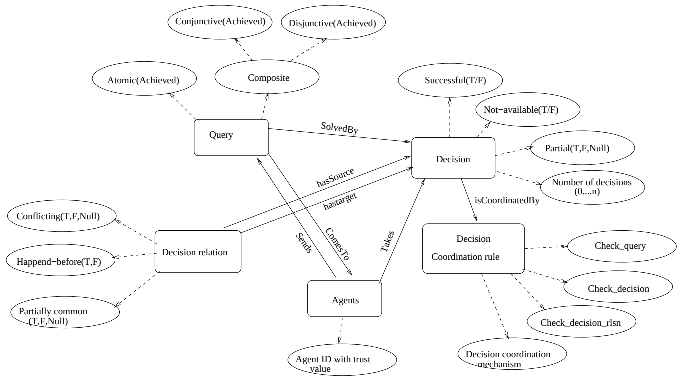

Fig. 4: Architecture of coordination ontology

Figure 4 represents the architecture outline of coordinate ontology.There are 5 classes

- Agent
- Decision
- Decision relations
- Query
- Decision coordination rule

classes have relationships between them and each class consists of a set of instances. The detail of coordination ontology can be found in our paper **[?]**.

- $Tprep$: Treatment plan repository is defined over medical domain M. Here for each disease treatment plan is defined. i.e. disease to treatment plan is a One-to-one mapping. It can be defined by function,
  $TPkb$: $D \longrightarrow TP$
  where D = { d_i |i=1....n } is a set containing all treatable diseases.
  and TP = { tp_i |i=1....n } is set of corresponding treatment plan. Function X is used to generate a report R,
  $X(d_i, TP_i)$ = R. This report is send it back to LPA.

B. Architecture of BNBA

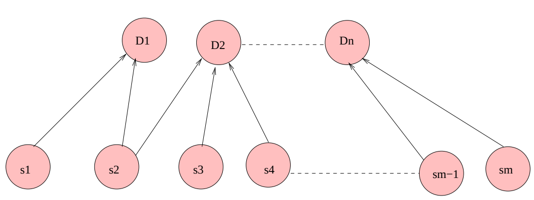

Fig. 5: Architecture of one Bayesian Agent

Figure 5 represent internal architecture of each Bayesian agent. Each Bayesian agent consists of a Bayesian Network by which Bayesian agents represent their knowledge base. Two types of nodes are their in the Bayesian network, Symptom(Sy) and disease(Ds). Symptom variables have three mutually exclusive state or severity value = $\{low, medium, high\}$ with value 2,6 and 9 respectively. Disease variables have two mutually exclusive states = $\{yes, No\}$.

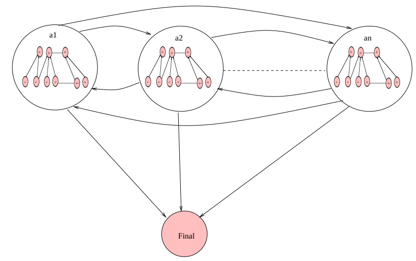

Fig. 6: Architecture of Bayesian Network of Bayesian Agent(BNBA)

Figure 6 represents the Bayesian network formed by Bayesian agents. where each Bayesian agents holds one Bayesian network. so number of mutually exclusive states of each Bayesian variables depends on number of different diseases in the Bayesian network of that agent. Number of mutual exclusive states of variable Final is union of total number of different diseases of all expert agents

C. Algorithm to construct Conditional Probability table if 'Final' variable in BNBA

As in $BNBA$ 'Final'node is conditionally dependent on all Bayesian Agent variables so to take decision among a number of alternative decision Conditional Probability Table(CPT) should be formed. This CPT should be formed by abiding rules of Coordination ontology. As we are handling decision of an expert agent in the form of disease name so there is no chance that two decision will be partially common or one decision may be partial in nature. So we have not consider those cases in order to construct the algorithm to form CPT of 'Final'variable. The algorithm is stated as below,

CPT_CONSTRUCT(m,count,Dc$\{\}$)
If (m/2) $\leq$ count $\leq$ m then
If $\forall$ d_i $\in$ Dc Conflict = False then
$\{$ **Make entry $\forall$ d_i $\in$ Dc in CPT of Final variable in BNBA as follows,**
p(d_i/Dc$\{\}$) = 1 and rest entries of the CPT = 0 $\}$
ElseIf $\forall$ d_i $\in$ Dc Conflict = True then
Grouping is done
If Groups are asymmetric then
$\{$ **Make entry $\forall$ d_i $\in$ Dc in CPT of Final variable in BNBA as follows,**
p(d_i/Dc$\{\}$) = $\{$ The Cardinality of the group in which di belongs $\times$ (1 / Count) $\}$
$\}$
Else
$\{$ **Make entry $\forall$ d_i $\in$ Dc in CPT of Final variable in BNBA**
as follows,
p(d_i/Dc$\{\}$) = $\{$ Value of the maximum trust value of the group in which
d_i belongs $\times$ (1 / summation of maximum trust value from each group) $\}$

}
EndIf
EndIf
ElseIf Count < (m/2) then
new (m - Count) number of expert agents are chosen and with the total m number of expert agent again call function CPT_CONSTRUCT(m,count,Dc{})
EndIf

Where m = Number of expert agent participate in discussion. count = Number of expert agent able to take decision among m expert agents. Dc{} = array of decisions of 'count'number of expert agents.

V. Problem formulation

Let in the system the set of expert agents A = { a_i |i = 1....m } is a team with a common objective. Let Sm is a global set of all possible sign symptoms of a patient. Now suppose by LPA a set of symptoms is taken from a patient P_t and the set of those sign and symptoms formed is S = { s_i |i=1...n } LPA sends this set S to all expert agents $a_i \in A$.
Their exists a logical network defined by a graph $G = (Ag, Ed)$ where A is agent corresponds to vertices and $e \in Ed$ corresponds to communication link. Depending on the received symptoms each expert agent arised some questionnaire. Let Q_j = { q_i |i=1...k } is a set of questionnaire arised by expert agent a_j. According to questionnaire LPA finds out other sign and symptoms of the patient P_t. Let 'α ' is a function responsible for selection of sign and symptoms depending upon q_i. α (q_i)= s where $s \subset Sm$. similarly, $\alpha(Q_j)$ = S_j = { s_i |i=1...l } where $S_j \subset Sm$ and S_j = $\emptyset$ can be true. LPA sends this S_j to agent a_j. All expert agent independently maps all these processed data on their KB(represented in the form of Bayesian network) which contains (s, v) ordered pair of symptoms and their possible value/ranges. A function β is defined over (s, v) to find out probable disease.
β ($\sum_{i=1}^{u}(s_i,v_i)$) = $d_j(t)$ where $n \leq u$ (As after getting answer of questionaries number of symptoms can increase to one expert agent)
Where $d_j(t)$ is the decision of expert agent a_j at time t. β returns information regarding disease on the basis of the following relations.
F: $2^{s \times v} \longrightarrow$ D (many to one relation)
Where D is the universal set of all possible disease of patient. so D = {d_i |i=1...w } Now all expert agent exchanges their decisions with other expert agents and according to other's decision they update their knowledge about the diagnosis using equation 1, If expert agent $a_i \in A$ take diagnosis decision $d_i(t)$ at time t, where $d_i(t) \in$ D Then agent a_i 's probability distribution over D at time 't'is,
$p_i(d_i(t), t)$ = Belief of the agent ai that disease $d_i(t)$ is the probable disease at time t. After message passing and sharing their decisions with other experts if agent a_i gets $d_i(t)$ is the decided disease of agent a_j at time t, Agent a_i's new belief at time twill be,
$p_i(d_i(t'), t')$ = $p_i(d_i(t), t)$ + ...(1)
Where ≥ 0 and (1 $\geq p_i(d_i(t), t)$ ≥ 0)

According to equation (1) belief of each expert agent is updated for each disease $d_i \in D$. After belief updating again decision making process is restarted and each expert agent takes decision independently. Let those decision can represented in the form of set Dc = { $d_i(t)$ |i= 1....o and o $\leq$ m }. Now coordination ontology is used to find out final decision among all alternative decisions of set Ds. A function CON is defined is CON(Dc) $\longrightarrow d(t)$ where $d(t)$ is the final decision at tth time. The belief value of final decision is $p(d(t), t)$.

The performance of the team or the utility of the final decision will be affected if summation of divergence between each agent′s belief and final decision belief increases.
As utility of the final decision $\propto$ total divergence between decisions of expert agents.
The divergence between the belief of final decision and a_i agents decision $d_i(t)$ at time t is ,
$|p_i(d_i(t), t)$ - $p(d(t), t)$ |= Δ_i(D, $p_i(d_i(t), t)$)
The bigger the above value mean higher divergence. The cost of $\Delta_i(\bullet)$ divergence to an agent a_i at particular time is
C(a_i, $\Delta_i(\bullet)$) $\longrightarrow$ R
Where R is the real number. Thus the overall optimization function to minimize is,

$$\sum_{a_i \in A} \int_{t=0}^{T} \mathbf{C}((a_i, \Delta_i(\bullet))\, \mathbf{dt}$$

To minimize this optimization function again expert agents communicates with each other by message passing to share their decision and update their belief. The discussion and updating of their belief process goes iteratively until optimization function get minimized. After getting the final decision with maximum utility let that is $dmax_i(t)$ $\in$D, where i may vary from 1 to w. This final diagnosis result is send to Treatment plan repository to generate report. Now if we recall the BDI architecture in section here Belief of an expert agent ai can be defined as $p_i(d_i(t), t)$ at time t. Desire of an expert agent is that each agent $a_i \in$ A tries to get a $d_i(t)$ at tth time with maximum belief value. Intention of every expert agent a_i's is to minimize Δi($\bullet$) at particular time. To reach to the intention each expert agent perform belief updating using message passing which is the action or plan of each expert agent.

VI. Case Study

We have done a case study on a medical domain of different types of fever. In the domain 7 types of diseases are there. Those are, D = { Urinary tract infection, Typhoid, Brucellosis, Lobar Pneumonia, Malaria, Kala-azar, Diseased liver }
and 22 types of symptoms of these diseases. Those are,
Sm= { Headache(A), Body pain(B), Joint pain(C), Vomiting(D), Chills(E), Poor appetite(F), Loose bowels(G), Nausea(H), Urine problem(I), Abdominal pain(J), Diarrhea(K), Nose bleeds(L), Cough(M), Skin problem(N), Sweating(O), Chest Pain(P), Depression(Q), Coated

tongue(R), Dark
Urine(S), Pale stool(T), Breathing problem(U), Anemia(V) }
In bracket we represent the abbreviations of corresponding symptom. e.g. Headache is denoted by A.
There are 8 expert agents we choose to participate in group discussion.
Each expert agent′s KB is represented in the form of Bayesian network formed by upper specified diseases and symptoms. KB may be different for different experts depending on their knowledge. Each symptom has a weight value ranges from 1 to 5. It varies disease wise and and expert wise.
In the Bayesian network of any expert agent following dependency of diseases on symptoms should be maintained,
Urinary tract infection $\rightarrow I \bigcap J \bigcap E \bigcap H \bigcap D \bigcap B \bigcap F \bigcap G$
Typhoid $\rightarrow A \bigcap J \bigcap H \bigcap D \bigcap F \bigcap L \bigcap E \bigcap I \bigcap K$
Brucellosis $\rightarrow O \bigcap V \bigcap A \bigcap Q \bigcap B$
Lobar Pneumonia $\rightarrow M \bigcap P \bigcap E \bigcap N \bigcap H \bigcap D \bigcap C \bigcap K \bigcap U$
Malaria $\rightarrow E \bigcap C \bigcap D \bigcap A \bigcap M \bigcap V$
Kala-azar $\rightarrow O \bigcap E \bigcap F \bigcap M \bigcap J \bigcap C \bigcap V$
Diseased liver $\rightarrow R \bigcap N \bigcap S \bigcap T$

Now suppose from a patient LPA takes symptoms and sends them as a set S = {I(9), J(6), E(9), H(6), D(9), L(6), O(6), M(2), P(9), C(6), U(2), T(2)}. In bracket severity value of every symptom (high(9), medium(6), low(2)) is given.

After a number of rounds of discussion final decision about the diagnosed disease is found as Lobar pneumonia. Simulations of discussion is shown in Figure 7 and 8. In figure 7 it is shown after time or round value 4 optimization function get minimized.

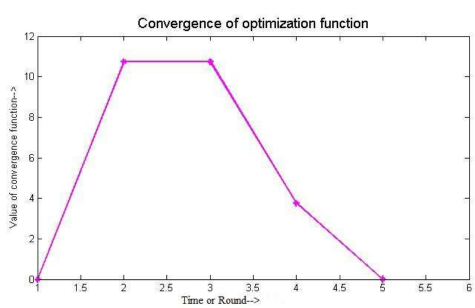

Fig. 7: Convergence of optimization function

In figure 8 it is shown that after time or round value 4, all experts belief value converges. that is their decision about the diagnosis become same.

VII. Conclusion

In this paper we propose a multi agent based group discussion mechanism to form a virtual medical board like system. Here each agent acts as expert physician, consists a knowledge base represented in the form of bayesian network. All expert physician independently disgnose a patient, communicate with each other with a common vocabulary i.e. Coordination Ontology to agree upon in a common decision. We also propose a

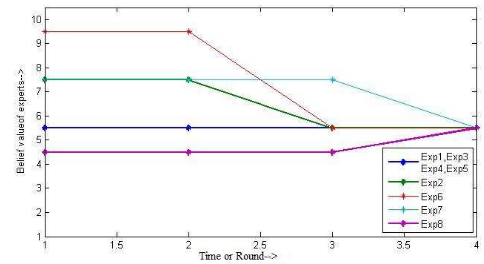

Fig. 8: Convergence of beliefs of all expert agents

optimization function, minimization of which increase the final decision utility. We also show minimization of optimization function by iterative group discussion with the help of case study by taking medical domain ‘Fever’. The BDI architecture of each expert agent is also shown. The future work will be

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