Fast growth of technologies and miniaturization of devices and sensors has led embedding computational capabilities ubiquitous, which impact all aspects of our everyday life. Ubiquitous Computing is a physical reality, which ensures the presence of computers and information everywhere. The ubiquitous presence of computers and information becomes more meaningful when they are user context aware in nature. This book investigates two important research issues of Ubiquitous Computing: Modeling user Context and Conflict Resolution.In this research a novel approach to model user context is introduced. The conflict resolving algorithms have been designed by integrating the contextual parameters like social, personal, temporal, activity, mood, ratings and social agendas with AI tools like rule base, fuzzy Bayesian probability and rough set theory. The usage of the proposed context model and conflict resolving algorithms is demonstrated in developing applications like Context Aware TV and Context Aware Mobile.

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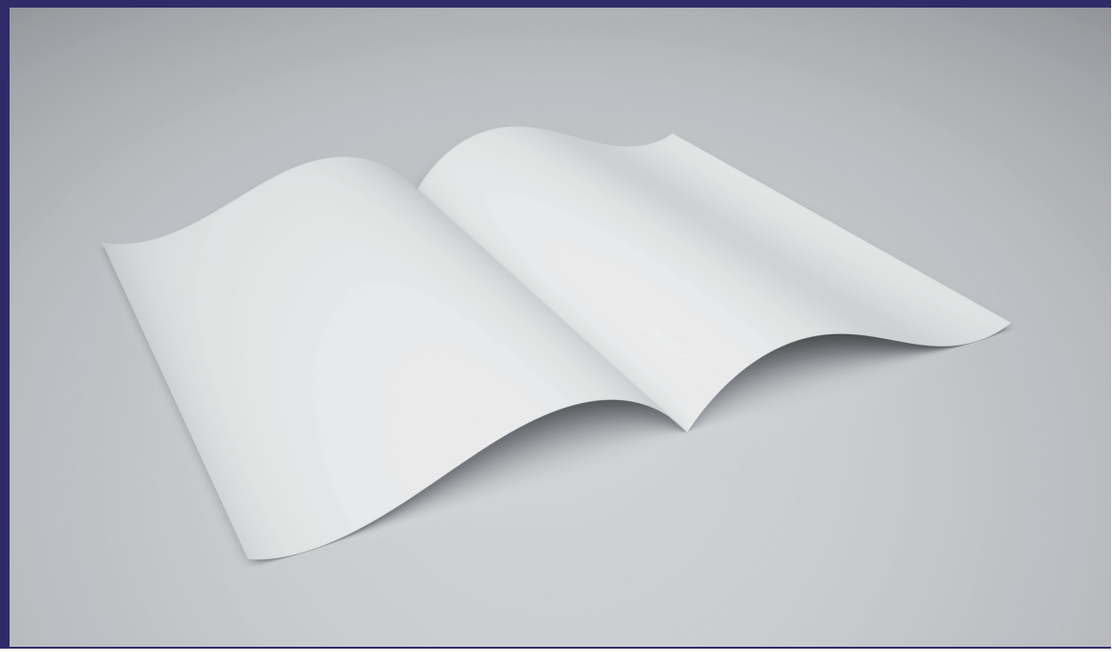
Research Work on Context Aware Computing



Thyagaraju G.S. Gowda

Context Aware Computing in Ubiquitous Computing Applications

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Acronyms

AI	Artificial Intelligence
AC	Air Conditioner
Avg	Average
AF	Age Factor
API	Application Programming Interface
BP	Bayesian Probability
BPBA	Bayesian Probability based Algorithm
BPAA	Bayesian Priority Assignment Accuracy
CAC	Context Aware Computing
CA	Context Atoms
CAMP	Context Aware Mobile Phone
CATV	Context Aware Television
CBCR	Content Boosted Collaborative Recommender
CEAR	Context Entity Attribute Relationship
ER	Entity Relationship
FD	Fitness Degree
FDTBA	Fuzzy Decision table based Algorithm
FDF	Family Dependency Factor
FRBA	Fuzzy Rule Based Algorithm
FBDGPA	Fuzzy Bayesian Democratic Group Preference Algorithm
FRGCRA	Fuzzy Rough Set theory based Group Conflict Resolving Algorithm
GM	Graphical Modeling
GMT	Greenwich Mean Time
GPRS	General Packet Radio Service
GPS	Global Positioning System
GR	Group Rating
IS	Information System
IND	Indescernibility Relation
IP	Internet Protocol
KVM	Key Value Modeling
LAN	Local Area Network
LBM	Logic Based Modeling
MAC	Media Access Control
MM	Markup Modeling
OnM	Ontology Modeling
OOM	Object Oriented Modeling
PDA	Personal Digital Assistant
PC	Primitive Contexts
PCC	Pearson Correlation Coefficient
RST	Rough Set Theory
RF	Role Factor
RFID	Radio Frequency Identification
SQL	Structured Query Language
SDF	Social Dominance Factor
Sim	Similarity
TV	Television
U	Universal Set
XML	Extensible Markup Language
UR	User Rating

1. Introduction

1.1 Overview

Technological advances in devices, sensors and wireless communication have led increasingly to the integration of sensors and devices with users and physical environment, leading to ubiquitous computing systems. Ubiquitous computing (ubicomp) supports a ubiquitous networked infrastructure of computing devices and sensors. It ensures the omnipresence of information with a special attention to activities of everyday life.

The presence of computing devices everywhere, becomes more meaningful and useful if and only if they can communicate with one another and with the user, to provide context based services. For example, it would be more comfortable for the user, if the mobile phone present in the meeting room can provide meaningful services (like going to silent mode automatically as soon as the meeting starts , allowing only emergency calls, answering to known and unknown calls suitably, linking to meeting related sites, etc., without interrupting the meeting session), based on context.

Thus, with the advent of ubiquitous computing environments, it has become increasingly important for applications to take full advantage of context aware computing to increase the satisfaction level of the user.

The contextual information, such as, environmental, social, task, spatio-temporal and personal information has to be considered to offer greater services to the user without any explicit requests and to resolve conflict among multiple services and multiple users. In addition, the digital devices like TV, AC, Mobile, etc., are evolving such that they can provide personalized and situation based adaptive services to user: a trend towards unlimited demand for support or use of context aware computing in providing human comfort. As a result, context must be well understood and modeled in an appropriate form. Thus the task of making the systems context aware has become central research issue of ubiquitous computing. This

necessitates the issue of modeling, storing, processing and interpretation of user context for design and developing the context aware ubiquitous applications.

Also, since the ubiquitous computing environments are pervasive and saturated with multiple sensors, devices, users and services, there will be a number of users interacting with a system simultaneously. Naturally this results in service conflict among users. The conflicts may be with the single user for multiple services, multiple users for multiple services and multiple users for single service. It will be more comfortable for the user if, the ubiquitous computing system can resolve conflict and recommend appropriate service based on the user context. This necessitates the issue of embedding conflict resolution capability into the context aware ubiquitous applications.

The research work presented in this thesis introduces generic methodologies for modeling user context and resolving conflict in single and multiuser environment. In summary, the motivation of the research is captured in the following demands or requirements of context aware computing:

- Demand for Smart Devices like Smart TV, Smart Phone, etc.
- Demand in the increase of the comfort level of user in terms of service provided by modern electronic gadgets and devices.
- Unavailability of models, for programming and designing context aware applications.
- The requirement of technologically aided conflict resolving methodologies in multiuser context aware environment.
- The requirement of algorithms to recommend services for the user based on personal and social context.
- The requirement of integrating social and personal factors for context aware service recommendation.
- Demand in design of context aware recommendation engine using a variety of AI tools like statistics, Bayesian Probability, Fuzzy Logic, Rule Base and Rough Set Theory.

1.2 Ubiquitous Computing

Ubiquitous computing (ubicomp) [Weiser 1988] is a type of distributed computing, which enhances the availability of information computing everywhere by thoroughly integrating different form of computers into everyday objects and activities.

Mark Wiser in his article **[1, 2]: "**The Computer for the 21st Century**"**, highlighted the future trend of merging of profound technologies into everyday life. Today the ubicomp applications are diverse in nature ranging from applications like smart mobile, smart TV, smart car to smart laboratories, smart museums, smart class rooms, smart home, etc. The ubiquitous computing environment may contain many devices with which user interact. These devices include:

- Laptop and desktop computers.
- Handheld devices like personal digital assistants (PDAs), smart mobile phones, smart tablet pc, smart video cameras, smart digital cameras, smart projectors, etc.
- Smart Appliances like smart washing machines, smart oven, and smart refrigerators.
- Other devices like smart TV, smart AC, etc.

In ubicomp world, the activities of user cause actions. For example, user relaxing in smart room can cause the window curtain to close, the light to dim, TV to turn off and mobile to switch over into silent mode.

Some of the ubiquitous computing applications and projects are discussed below:

1. Ubiquitous Health Care **[3]:** In this system, a patient is continuously monitored with an array of sensors placed on the patient's body. An interface collects data and sends this data to the monitoring system. Interface by exploiting the technologies like RFID, GPS, GPRS, Bluetooth, Zigbee, etc., remain connected to the monitoring system always.
2. Ubiquitous Navigation System **[4]:** The system makes use of technologies like GPRS, GPS, Wireless LAN (wifi), Mobile IP, RFID and Bluetooth. It provides the information of the location (like latitude, longitude, location name, path to different location from the current location, etc.) to the user.
3. E-Class Room: The software provides audio and video recording of lecture sessions. It converts the audio recorded into notes. It establishes an interaction

between student and teacher. It utilizes the different context like location and class schedule to predict the next class.

4. Cyber Guide **[5]:** The cyberguide project focuses on how portable computers can assist in exploring physical spaces and cyberspaces. It is a replicate of human tour guide using mobile and hand held technology. It makes use of location information to track the user / suggest establishments and maintains history of places visited, for future.
5. Easy Living **[6]:** At Microsoft Research, the Ubiquitous Computing Group has created a system called Easy Living that is a prototype of architecture and technologies for ubiquitous computing. The Easy Living system demonstrates many of the capabilities of ubiquitous computing like mobile computing, wireless communication, context aware computing, location sensitive computing and disaggregated computing.
6. Stanford iroom **[7]:** A test bed of smart room with spatial, socially aware, deep physically integrated and coordinated autonomous systems. The room is fixed with multiple large embedded Displays, Laptops and Heterogeneous handheld devices.
7. Labscape **[8]:** A ubiquitous biology lab with sensors and PCs. It is a smart environment that is designed to improve the experience of people who work in a cell biology laboratory.

1.3 Context Aware Computing

One of the distinguishing features of Ubiquitous Computing is that the computation is a part and parcel of everyday life. The computing services required for user depends on user's social and personal context. Thus, the ubiquitous computing systems can provide more meaningful and useful services provided, the systems are context aware in nature. Ubiquitous Systems are a store house of sensors and devices without context aware computing. It is the context aware methodologies which

- makes ubiquitous systems aware of situations of interest.
- enhances services to users.
- personalize and socialize applications.

Albrecht Schmidt in his report **[9]** highlights the importance of context aware computing as: **"**Context is essential for building usable Ubiquitous Computing systems that respond in a way that is anticipated by the user**".**
Context Aware Computing is defined as**: "**The computing paradigm to store**,** process and predict the context with the intention of providing context based rational services**".**

1.3.1 Definition of Context:

As per the literature survey made **[1-47],** most of the researchers and standard dictionaries define context as**: "**The information that describes the situation or circumstances of an entity in which an event occurs**."** This definition clearly implies that context is related to an entity**.**

Dey and Abowd (2000) have also confirmed this by defining context as**: ''**Any information that can be used to characterize the situation of an entity**.** An entity is a person**,** a place**,** or a physical or computational object that is considered relevant to the interaction between a user and an application**,** including the user and application themselves**.'' [10, 11]**

Pascoe defines context as**: "**Context could be generally described as the subset of physical and conceptual states of interest to a particular entity**."** Contextual information is related to a certain entity**. [12]**
Context in this report is represented as a set of attributes which characterizes the situation of an entity**.**
For Example the context of user can be represented as:
User_Context = {User_Name**,** User_Role**,** User_Age**,** User_Interest**,** User_Mood**,** User_PhysicalPosture**,** User_PhysicalHealth**,** User_ Activity**,** USer_Location**,** Date**,** Day**,** Time**}.**

A set of attributes are said to describe a user context**,** if and only**,** if they are capable to answer the questions related to identity**,** location**,** time and activity of user**.**Table1 illustrates some of examples for context and non context set**.**

Table1: Context and non context set of attributes

Set Of Context Attributes	Identity	Location	Activity	Time	Context	Example
Name, Role	1	0	0	0	No	Rohan is Father
Name, Role, Time	1	0	0	1	No	Rohan is Father during Morning Hours
Name, Time, Activity	1	0	1	1	No	Rohan is Father and Doing Yoga during Morning Hours
Name, Time, Activity, Location	1	1	1	1	Yes	Rohan is Father and Doing Yoga during Morning Hours in the Living Room of his House.

Note : *1- Provides related information 0* ***:*** *Does not provides the related information*

The context attributes can be classified into two categories:

1. Indispensable Attributes
2. Dispensable Attributes

The indispensable attributes are those which provide all the mandatory information to describe context. All other attributes are dispensable attributes. But dispensable attributes adds more flavor to the indispensable attributes and will be useful for providing socialize and personalize services. Table2 illustrates some example of dispensable and indispensable attributes.

Table2: Dispensable and Indispensable Attributes

Context	**Indispensable Attributes**	**Dispensable Attributes**
Rohan is Father and doing yoga during Morning Hours in the living room of his house	Name, Role, Activity, Location	Nil
Rohan is Father, his health is normal and doing yoga during Morning Hours	Name, Role, Activity, Location	Health.
Rohan is Father, his sex is male, health is normal, physical posture is running and doing yoga during Morning Hours.	Name, Role, Activity, Location	Health ,Sex
Rohan is Father, his sex is male, health is normal, mood is normal, and eye sight is abnormal, and doing yoga during morning hours in the living room of his house.	Name, Role, Activity, Location	Health, Sex, Eye Sight, Mood.

1.3.2 Properties of Contextual Information: The information related to context of an entity is termed as contextual information with respect to that entity. Some of the properties (as reported by Dr.Ing.Thomas Springer in his lecture notes) to list are as follows:

1. **Context information may be static or dynamic:** The context of any entity may or may not change with respect to time. Context which represent the

dynamic information are said to be ***dynamic context***. **Example:** Age of person, User time point, user's location, user friends, user intention, user mood, etc.

The context which represent the static information are said to be static context. **Example:** Name, Date of Birth, User Role, User Priority etc. However the static information like name, date of birth, priority of user can be represented as information with change frequency zero.

2. **Context information creates History:** Since context varies from time to time, a history of user/entity context will be created with respect to time. The history of context can be utilized for predicting the future context.
3. **Quantity of Context information is large:** Since context is a set of multiple attributes, when any one of the attributes changes it results in the change of context. This results in the increase of quantity of context base.
4. **Incorrectness in Context Information:** This is due to inexact sensor information, measurement failures or due to wrong assumptions for derivation and interpretation.
5. **Multiple sources**: Same contextual information can be gathered in different ways. Eg: Location of a person can be gathered using the data provided by GPS, Wi-Fi, Bluetooth and GPRS.
6. **Relevance of Context Information :** It depends on the following two factors

   1. Capturing time: The relevance will be maximum at capturing time. It decreases constantly. Example: Location of a mobile user and user interest on particular TV program.

   2. Location: The temperature measured depends on the location. The relevance will be maximum at capturing place and decreases with distance.
7. **Context Information is Multidimensional / Heterogeneous:** The context information may be personal, physical, technical or social in nature.
8. **Context information is Distributed:** The contextual information occurs everywhere / all the time. It is ubiquitous, pervasive and omnipresent.
9. **Context information is Unforeseeable:** Since any information can be relevant as context the context information is unforeseeable.

1.3.3 Categories of Context: The context can be categorized into different types based on the information they carry. Following are some of the list (as reported by Dr.Ing.Thomas Springer in his lecture notes) of information based context.

1. **Computing Context:** It provides the information related to the computing like processing speed, memory, free disk space, necessary software, OS services, internet connection, utilities, etc.
2. **Network Context:** It provides the information related to networking like connection, bandwidth, LAN, WAN, WIFI, Bluetooth, signal strength, etc.
3. **User Context:** It provides the information related to user like name, role, location, priority, activity, mood and other user's information.
4. **Physical Context:** It provides the information related to environment like light intensity, temperature, weather conditions, sound level, etc.
5. **Time Context:** It provides the information related to time such as time of day, week and Month.
6. **Sensor Context:** It provides the information related to the different sensors like location, time, temperature, noise, light intensity, etc., to perceive the context of environmental input. The sensor context includes the information like active, inactive, damaged, out of order, switched on/off, resolution, relevance, etc. The sensors provide the raw contextual data to the drivers or widgets attached to the sensors.
7. **Device Context:** It provides the information related to the different actuators (TV, AC, FAN, Light, Mobile, etc.) like device input and output capabilities, memory, software support, available services, service preferences etc., to provide meaning full service to the users. Devices are the service providers for users.

The context can be further divided into primary context and secondary context. The primary or low level context refers to the environment characteristics, which can be gained directly from sensors. Example: location, time, nearby objects, network bandwidth, orientation, light level, sound and temperature. The sensors can either measure physical parameters in the environment or logical information gathered from the host (example: Current time, GSM cell, selected action) and the sensors

are called physical or logical correspondingly. The secondary or high level context refers to a more abstract context, which is derived from the primary context. Example: the user's social situation, activity or mental state.

1.4 Thesis Outline

The thesis is structured in the following way. In chapter2 the literature survey made to investigate the research issues is presented. In chapter3 an overview of research problem is presented. In chapter4 the research issue Modeling User Context is discussed. Chapter5 introduces the proposed generic architecture of context aware systems. In chapter6 the research issue related to algorithms for conflict resolution and recommending services are discussed. The conclusion in chapter7 summarizes the contributions made in the thesis and future scope of the research.

2. Literature Survey

Context aware computing finds its origin as early as 1992 when the, Want et al., introduced the Active Badge Location System which is considered to be one of the first context aware applications. The application used infrared technology to determine the user location. The information was used to forward the phone calls to a telephone close to the user. Based on the location context a couple of location aware tourist guides was developed in the middle of 1990s (Abowd et al., 1997; Sumi et al., 1998;Chevrest et al., 2000). All the context aware applications designed during mid of 1990s were based on location context. In 1994 Schilit and Theimer used the term context aware to describe the context as location, identities of nearby peoples, objects and changes to those objects. In 1997 Rayen et al., used the term context to describe the user's location, environment, identity and time. A Dey and Abowd (2000) moved a step forward and used the term context as information to describe the overall situation of entities. Zimmerman (2007) et al., described the context in terms of five categories: individually, activity, location, time and relations. Bolchini et al., (2009) defined context as the set of variables that may be of interest for an agent and that influence it actions.

Over the last decade, most context aware research, aimed on, have been done on consumer product like smart TV, smart mobile, smart car, smart homes, intelligent office, interactive tourist guide, intelligent environment, ambient intelligence etc. It was found that the tendency of context definition was getting more general and wider as time passed. In the last decade the focus of the context aware applications is shifted from the simple situation aware to personal and social aware. Personalization and Socialization has really gained importance with always connected services in the context aware applications. As a result of this the recommendation engine of context aware ubiquitous systems **[53-77]** are changing their role from simple content and collaborative based recommendation to personal and social based recommendation. Artur Lugmayr [2009] in his research articles **[78,79,80]** stresses the need of integration of Natural interaction, personalization, socialization, smart metadata, wireless technology, ubiquitous systems, pervasive computation and embedded systems.

Since ubiquitous computing systems are pervasive and involve multiple users and services, naturally it results in conflict among multiple users and services. The conflict can be resolved more meaningfully if the system are personal (individual) aware and social (group) aware.

The research work presented in this thesis, addresses the issues related to the user context and conflict resolution with respect to personalization and socialization. The research work models user context in terms of entities and their attributes that describes personal and social situation of user. And the personal and social context is considered as a prime input for conflict resolution.

The literature survey presented in this thesis is done with respect to two research issues: Modeling User Context **[10-47]** and Conflict Resolution **[48-115]** from the perspective of user's personalization and socialization.

In the following section the thesis discusses the research issues and research gap identified.

2.1 Modeling User context: Modeling Context is a fundamental step for every context oriented adaptive application and also, for the design and development of context-aware systems. It consists of the analysis of contextual information contained in the system, for the purpose of representing context in an abstract form, on the level of data structure as well as the semantic level. Several approaches were proposed for the representation of context. Strang et al **[14,15]** made a survey and comparative study of models with respect to different parameters like distributed composition, partial validation, richness and quality of information, incompleteness and ambiguity, level of formality and application to existing environments. The models they considered were key value models, markup scheme models, object oriented models and ontology based model **[16,17]**. At the end Strang et al., concluded that ontology makes a best description of context compared to the other methods with respect to the parameters. But the ontology model shows partial support in terms of expressiveness, completeness and understandability which are very important in designing context aware applications.

The research work presented in this thesis aims in, designing a novel model to represent user context with better expressiveness, completeness and understandability. The following section discusses a survey and comparative study

of the relevant context models in terms of expressiveness, understandability and completeness.

Key Value Model:

In his paper **[16]** Riva describes context representation using key-value pairs. An example is the triplet ***<****noise=medium, light=natural, activity=walking****>*** which defines the context type **"***walking outside***".** Key-value models represent the simplest data structure for modeling context by exploiting pairs of two items: A key (attribute name) and its value.

***Research Gap 2.1.1*:** Key-value model is easy to manipulate, but it is not convenient for representing the complicated structure like context involving multiple entities with derived contexts. It does not permit a good reasoning on context data to infer properties or more abstract context information (*eg: deducing user activity, user preference, service conflict, etc., by combining sensor readings*). For example, one can express the meeting room scenario using key value model as follows:

<sensor_ID = Location Sensor>
<location = meeting room>
<sensor_ID = USer Sensor>
< #of users = 5>
<user1_id=25> <user2_id=26 > <user3_id=4> , <user4_id=6> ,<user5_id=5>
<user1_Role= Chairman> <user2_Role= Member><user3_Role= Member>
<user4_Role= Member><user4_Role= Member><user5_Role= Member>
<sensor_id =Time Sensor> <time = 10.30AM GMT>
<sensor_id=Activity_Sensor><user1_Activity=Meeting><user2_Activity= Meeting><user3_Meeting=Meeting><user4_Acivity=Meeting><user4_Activity = Meeting><user5_Activity= Meeting>
<Sensor_ID= Temp_Sensor>< Temp_Value= Very High>
<Device_ID = AC> <Device_Status=ON> <Device_Temp= Normal>

In the above example, the key value model describes the context of meeting room, in which five users are present out of which one user is chairman and other users are members, time is 10.30 AM GMT and activity is Meeting. The current environmental temperature is very high. The AC is adjusted to Normal temperature.

In the above example it is clear that the key value model does not provide scope for establishing the rules among sensors, devices and users. For example it does not expresses the rules or association between:

- Temperature Sensor and AC
- Time sensor and activity Sensor
- Activity sensor and AC
- One user with the another
- User with the AC or Sensor

Since, the model uses the text for representing all type of sensors, devices and users its expressiveness is poor as compared to the model based on graphical symbols. It expresses successfully only the primitive context (like location, user_id, sensor_id, device_id, etc) through matching but fails to express the derived context (like user social situation, condition of meeting room, user's physical and mental state). The model is incomplete in the sense it does not provide complete details of the sensors (type, source of data, make, range, condition, etc.), users (profile, source of profile, personal context and social context) devices (type, make, service details, range and condition) and location (type, sensor used, range and values). If one tries to achieve completeness it becomes more complicated to understand.

Also it does not provide reasoning for conflict if any, among different users. There are no proper hierarchical relationships among different entities. It supports only exact matching and no inheritance or deduction.

Markup Schema Model :

The proposed approach in the papers **[23,24]** makes use of Markup Scheme models to represent the Context. Markup scheme models use XML-based representations, to model a hierarchical data structure consisting of markup tags, attributes, and contents. The example below illustrates the representation of user context: **"***user is in living room of his house***"**.

```
< Person rdf :ID = "Raju ">
        <locatedIn rdf: resource = "#Home"/>
</Person>
<Building  rdf : ID = "Home">
        <contains rdf :resource = "#LivingRoom"/>
        <contains rdf:resource = "#Raju"/>
</Building >
<Room rdf :ID = "LivingRoom">
        < Contains rdf :resource = "# Raju "/>
</Room>
```

Research Gap 2.1.2: This approach requires knowledge of markup languages. The model is script oriented. One needs to have scripting knowledge for better modeling of context. The complexity of script representation increases based on the complexity of user context. Modeling effort is more. Annexure3 provides some of examples, to represent the modeling of user context using xml markup language.

As per the survey and comparative analysis made by the Strang et al., **[15]** the model has good support for the features like simplicity, extensibility, reasoning, completeness and applicable to existing environment. The model is simple from the designer perspective, as it allows the designer to define his own tags. The model can be extended or appended at any time. But this reduces the expressiveness and understandability from the end user perspective, as the size of the script increases. The user must go through the hundreds of lines and tags in order to understand the simple representation of user context. As a result the model has got low support for features like understandability and expressiveness. It is not a light weighted as its size increases as the complexity of context increases.

The problem of aggregation is more complex where in one has to create a separate file for each primitive context and then aggregate all the files into a single file. But the resultant file does not derives or deducts any meaningful secondary context instead it just lists all the primitive context values in to a single file.

An example with user context shows how this aggregation works: the idea is to have several XML documents describing the each user primitive context.

```
<!-----userLocaltion.xml>
        <user_Location>
                <Location> Living Room</Location>
                 <Sub_Location>Chair#2</Sub_Location>
        </user_Location>

<!-----userMood.xml>
        <user_Mood>
                <Mood> Normal</Mood>
        </user_Mood>

<!-----usernActivity.xml>
         <user_Activity>
                <Activity> Relaxing</Activity>
          </user_Activity>

<!-----userIntention.xml>
```

```
        <user_Intention>
              <Intention> Watching TV</Intention>
        </user_Intention>
<!-----userParticpatingTime.xml>
        < Participating_Time >
              <Interval Type="Absolute" >
                    <From>2012, 04, 12, 21.32</From>
                    <To> 2012, 04, 12, 22.30</To>
              </Interval>
          Participating_Time>
```

And one aggregated file listing all the documents:

```
<<!-----userAggregatedConetxt.xml>
  <Aggregated_Context>
        <location>userlocation.xml</location>
         <Mood>usermood.xml</Mood>
         <Activity>userActivity.xml</Activity>
         <Intention>userIntention.xml</Intention>
         < Participating_Time >usermood.xml</ Participating_Time >
  </ Aggregated_Context >
```

As shown in the above example, the markup language supports aggregation across multiple files and also it does not derives or generates a new secondary meaningful context instead it just list all the primitive context in a single file. The model has got low support for the feature expressiveness (from the perspective of the end user in the open environment). Since the model uses the text and tags for representing all type of information like primitive context, sensors, devices and users its expressiveness is very low as compared to the model based on graphical symbols. Like key value model it also expresses successfully the primitive context. But the model shows more complexity in expressing the information like derived secondary context and the multiple user context which involves multiple devices, sensors and users.

Object Oriented Models:

The research work presented in the literature **[33, 34, 35, 36 and 40]** make use of object oriented modeling technique for representing context. In these approaches the context of entity is represented using class and its members. Each class defines a new context type with associated access functionalities. The research work

presented in the above publications makes an attempt to model the context aware applications for mobile and distributed systems using class diagrams.

Research Gap 2.1.3: The class diagram gives the high-level design for the programmer to develop the system. The model expressiveness is partial. The model expresses the high level abstract details. But it hides the low level details because of encapsulation. It does not reveal or expresses the instance of user context completely in an open environment as viewed by the end user. Encapsulation is a drawback as the contexts are invisible. For example in a living room scenario the model fails to give the complete details of user context like role of the user, location of the user , mood of the user ,activity of the user , preference of the user ,status of the door , etc. Rather the model provides an abstraction of user context in terms of classes (user, sensor and device) and associated functionalities (get and set methods).The model is complex in terms of end user understandability and expressing the conceptual context in detail. Fig1 illustrates the representation of user context using class diagram.

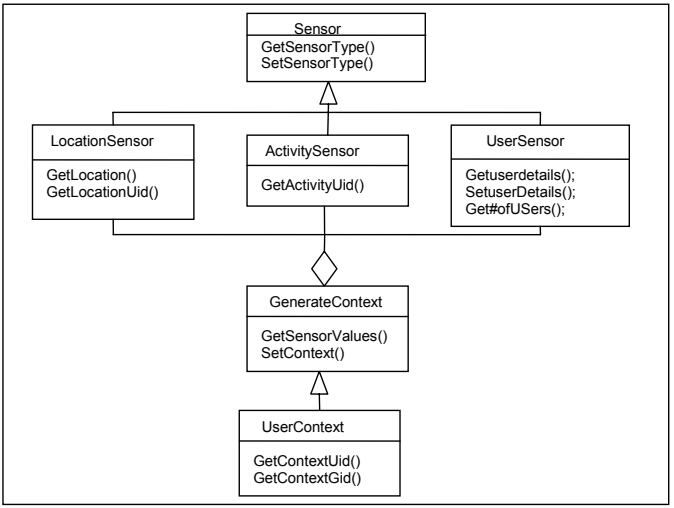


Fig1: Class Diagram to represent user context

Logic based Models: Logic is a formal system for manipulating facts so that the true conclusion can be drawn. In Logic based models **[41, 42, 43, 44 and 45]** the context is represented by making use of facts, conditions, rules and expressions.

Example1: The example below represents the context, "Rohan enters living room in late night and TV gets on" using Propositional logic.

P: Rohan enters living room

Q: Time is Late night

R: Switch On TV.

Logic Representation: $P \wedge Q \Rightarrow R$

Example2: The example below represents the context "Rohan is watching TV during late night in living room", using predicates and relations.

Location (Rohan,Sitting_On_Sofa,Living_Room)

Activity (Rohan, WatchingTV, Living_Room)

Time (LivingRoom,"=",Latenight)

Example3: The example below gives the first order logic based definition of the context, "current context of user inside the living room".

Location(Person,LivingRoom)
CanUSeChannel(Person,Channel);
∀device requires_device[channel,device]
Located_near[person ,device] ∧ permitted_to_use[person,device]

Example4: The example below is used to describe the context, "Academic Meeting in a board room within a college main building, and having at least four faculty members" in higher order logic using existential and universal quantifiers.

$AcademicMeeting \sqsubseteq Activity \sqcap \geq 4\ hasMember$

$\forall\ hasMember.Faculty \sqcap \exists\ hasLocation.(BoardRoom \sqcap CollegeMainBuilding)$

The systems like Mobile Gaia**[41]** and Gaia represent context using predicates [Chetan et al. 2005; Ranganathan and Campbell 2003] like Context(<ContextType>, <Subject>, <Relater>, <Object>), where <ContextType> is the context type that the

predicate is describing; <Subject> is the person, place, or physical object the context is concerned; <Object> is the value associated with the <Subject>; and <Relater> links <Subject> and <Object> by means of a comparison operator (=, >, or <), a verb, or a preposition.

Some of the context predicates used by Ranganathan.A. etal., **[42]** are as follows:

Location (Chris, entering, room 3232)
Temperature (room 3232, "=", 98F)
Time (Newyork,"<",12:00 01/01/01)

The article makes use of first order logic to represents the rules. Some of the rules used are given below:

Rule#1
ThereExists (Person, x) Location(x, Entered, 2401).
PlayWelcomeMessage ().
Priority: 1.

Rule#2
Location (Manuel, Entered, 2401) OR Location(Chris,Entered, 2401).
ShowInterface().
Priority:1.

Rule#3
Location(Manuel,In, 2401).
PlayRockMusic().
Priority:1.

Research Gap 2.1.4: As illustrated in the above examples the logic based models are more abstract in nature and hence it provides very high level details. It provide very less support towards completeness i.e. the model does not provide low level details of sensors, devices and user. It provides high degree of formality. They do not offer simple functionalities and the rules are not straightforward to specify and depends on the adopted type of logic. The model is often used in centralized context management. The relations between the context entities cannot be easily described. The model complexity is more in expressing and understanding the context containing multiple entities and conflicts. From the end user perspective the logic model provides very less support for the feature like understandability, expressiveness and completeness.

Ontology based Models: The models uses ontologies based on every day real life knowledge to represent user context. The model is capable of expressing complex relationships and data validity. The model is more general and is applicable for any specific domain. The model is easily usable and manageable automatically from the perspective of designer. But when it comes to the perspective of the end user, the model provides very low support for the features like understandability and partial support towards completeness. Even for designer the model provides less support in terms of source of information, like what type of information is getting generated from which type of sensors or devices or users. In addition the model does not provide the information related to the physical and database architecture that is required to design and develop specific context aware applications.

The papers **[46,47]** make use of anthologies (ontology based model) to represent context. Fig**2** is an illustration [**46**] of modeling the user context for home domain using generic ontology.

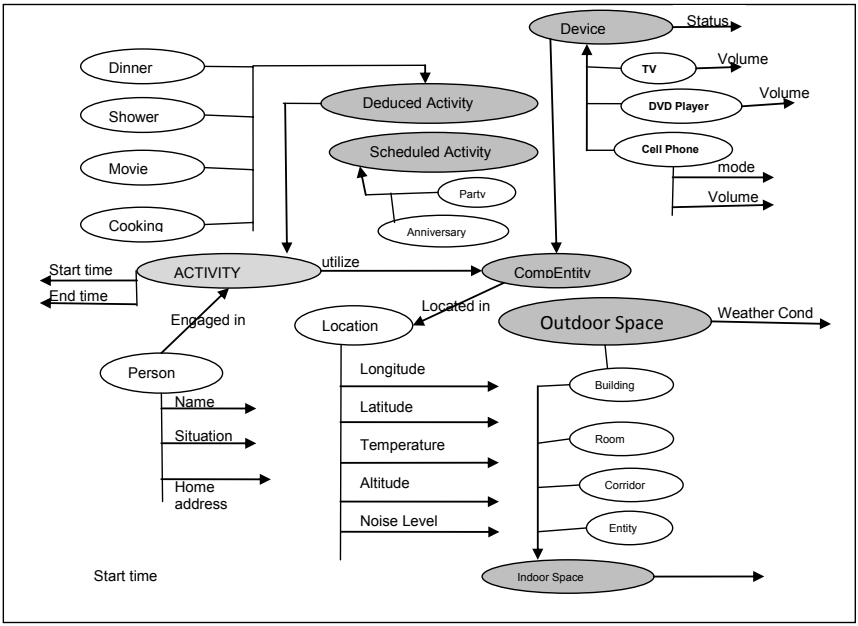


Fig2: Modeling the user context in home using ontology **[Source: Gu eta al. (2005)]**

Research Gap 2.1.5: The ontology based context modeling is more generic which necessitates the need of more context aware computing domain specific ontology modeling. Context aware computing environments are usually saturated with entities like sensors, devices and users. There are no specific symbols or notations, to represent the context entities like sensors, devices and users which make the understandability more complex for the end user. It provides partial support towards richness and quality of information. This is because it does not make use of any domain specific symbols and associations to represent the context entities like sensor, devices, user and to represent the specific relationship between them. Rather it makes use of more generic symbols like ellipse, arrows and lines to represent all types of contexts entities. The generic symbols make the model more abstract in terms of understandability from the perspective of end user. One has to rely upon the text and limited symbols used to understand the context represented. The model has got limited support for the features like aggregation and source of information.

2.2 Conflict Resolution in Context Aware Computing based Applications.

In the literature, the problem of conflict resolution or service recommendation is resolved, using two different approaches: Content Boosted Collaborative Approach and Decision table based approach. In both the cases, the factors like item quality, user rating and user priority are used for resolving the conflict and hence recommending the services.

1. Content Boosted Collaborative Approach: The content boosted collaborative approach is a hybrid of content and collaborative based conflict resolution and service recommendation system. In content based conflict resolution one tries to resolve conflict by considering the past most frequently recommended items or services. In collaborative based conflict resolution one tries to resolve conflict by considering the more similar users. In a hybrid technique both user rating and similarity among user is considered for resolving conflict.

The research work presented by Prem Melville,etal **[48],** Zhimin Chen, et al **[49]** and Choonsung Sing , et al **[50],** proposes the recommender systems which make use of

content (item rating) boosted collaborative (collective user or group rating) to predict new items of user interest. In the user-based content boosted collaborative filtering recommendation system, the user ratings data are used to determine the similarity between users.

In the literature most of the research works [**48,49,54,62,73,75]** make use of Pearson Correlation Co –efficient (PCC) to determine the similarity. The reason to prefer PCC is that it avoids the problem of grade inflation.

The similarity between user **u** and user **v** can be defined as following:

$$\textbf{Sim (u,v)} = \frac{\sum_{i \in Iuv}\left(R_{u,i} - \bar{R}_u\right)\left(R_{v,i} - \bar{R}_v\right)}{\sqrt{\sum_{i \in Iuv}\left(R_{u,i} - \bar{R}_u\right)^2 \sum_{i \in Iuv}\left(R_{v,i} - \bar{R}_v\right)^2}}$$

Where

$R_{u,i}$, is the rating of the item i given by user u

$R_{v,i}$ is the rating of item i given by user v

$\bar{R}_u$ is the average rating of user u for all items

$\bar{R}_v$ is the average rating of user v for all items

I_{uv} is the set of items rated by both user u and v.

If N_u denotes the current user ***u's*** neighbor set. His rating for item ***i*** will be predicted as follow:

$$\mathbf{P}_{(u,i)} = \bar{R}_u + \frac{\sum_{v \in Nu}\left(R_{v,i} - \bar{R}_v\right) * Sim(u,v)}{\sum_{v \in N_u} |Sim(u,v)|}$$

Where

$\bar{R}_u$ represents the average score of user **u** for his rated items

$R_{v,i}$ represents the rating on item **i** given by user **v**

$\bar{R}_v$ represents the average score of user **v** for his rated items

Sim(u,v) is the similarity between user **u** and **v**

Example: Consider the situation where in, the three users are present in the living room and their preferences are as illustrated in the table below:

Table3: Computation of Predicted Ratings

User	I1	I2	I3	$\bar{R}_u$	$P(u,I_1)$	$P(u,I_2)$	$P(u,I_3)$
U1	50	40	10	33.33	34.62297	42.0373	23.32577
U2	25	45	30	33.33	34.56449	40.1018	25.32054
U3	30	10	60	33.33	32.61422	25.36935	44.18602
U4	30	15	55	33.33	30.3919	24.144	45.52571

Pearson coefficient will be calculated for all the items for given set of users. For example $P(u_1,i_1)$ measures the amount of similarity of user1 for item1 with the remaining users say user2,user3 and user4. In the above example (Table3) the amount of similarity of user1 with remaining user for item1 rating is 34.62297 percentage.

The above methods have been tested for internet applications to recommending items like books, electronic gadgets, movie, music, etc. Choongsun Shin et al has used the hybrid of collaborative and content based methods by exploiting service profile and user preferences to resolve the conflict for media services for recommending movies and music.

Research Gap 2.2.1: The Content Boosted Collaborative Recommender (CBCR) systems are based on the similarity between users in terms of user's priority and item rating. But the user rating and user priority changes dynamically based on the user context. For example the user, say Rohan, whose role is father in his family always dominates other and have naturally high priority. But the same person whenever he is in different social situations like in meeting room of the office, in class room of the college, in canteen with friends,etc., his role and priority changes. The CBCR systems are very specific and resolve the conflict by considering only user rating and priority all the time without considering his personal, physical, social, environmental and time factors.

In order to give the more meaningful recommendations one has to consider the user context like personal context (user rating, user priority, age factor, mood, interest,

activity, user satisfaction), physical context (health, physical posture) and social context (role, social dominance factor, social group, social activity) in addition to the environmental and time factors for resolving conflict and recommending services.

2. Decision Table Based Approach:

In this approach **[51]** the fuzzy rules, including the conditions and actions to be taken, will be stored in decision table (A table derived by applying the concepts of Rough Set Theory) as illustrated in the table4.

Table4: Decision Table

Conditions				***Actions***	***Fuzzy Rules***
Features	***Application***	***Specification***	***Price***	***Decision***	
Good	Middle	Good	Middle	Recommend	R1
Great	Great	Good	Poor	Don't Recommend	R2
Middle	General	Good	Great	Recommend	R3

The decision table as illustrated in table4 is used to recommend the item (say mobile), based on the conditions like features, application, specification and price. The fuzzy rules used to make the decisions are as follows:

Rule 1: If Features is "Good", Application is "Middle", Specification is "Good" and Price is "Middle", then recommend.

Rule 2: If Features is "Great", Application is "Great", Specification is "Good" and Price is "Poor", then don't recommend.

Rule 3: If Features is "Middle", Application is "General", Specification is "Good" and Price is "Great", and then recommend.

Research Gap 2.2.3: The proposed recommendation system, based on fuzzy rules and decision table, is designed for the system which is not context based. In addition the conditional attributes used in the decision table do not contain any information related to the user context like personal context, physical context and social context. Rather the system is item characteristics oriented.

2.3 Research Challenges Identified:

1. Enhancement of existing context modeling approach to represent a user context using domain specific notations, for entities (sensors, devices and users) and relationship between entities, from the perspective of end user and designer. The model must be simple to understand such that
    i. It can be used to represent user context effectively with ease using graphical symbols and notations.
    ii. It can be used to explain the concepts of user context which is abstract in nature with improved level of understandability to end user.
    iii. It can express all possible user contexts completely.
2. To propose a new set of algorithms for conflict resolution by considering the personal (age, health, mood, activity, intention and interest) and social (role, location, time and activity) contextual factors.
3. To enhance the performance of existing conflict resolving algorithms making use of AI tools like Fuzzy logic, Bayesian Network, Rule Base and Rough Set Theory based Decision Table.
4. Performance Analysis of conflict resolving algorithms.

3. Problem Definition

Title of the Research: ***Context Aware Computing in Ubiquitous Computing Applications***

With the advent of ubiquitous computing it has become increasingly important for applications to take full advantage of context aware computing to increase the comfort level of the users in everyday life. Even though the number of context aware applications is increasing day by day along with the users, till today there is no generic programming paradigm to design and develop context aware applications. This problem could be solved by introducing the generic methodologies for context modeling, capturing context, storing context, context processing, conflict resolution and context aware service recommendation. In line with this research trend, the research presented in this thesis addresses the following issues:

Research Issue 1: Modeling User Context

Modeling Context is a fundamental step for every context oriented adaptive application and also for the design and development of context-aware systems. Also since most of the context aware applications (like Context Aware TV, Context Aware Mobile, Context Aware Class Room, etc) is user oriented there is a need to model the user context specifically. Today the related work on modeling context is more abstract, complex and laborious. No models are complete enough to express the situation of users in terms of sensors and devices along with user's social and personal factors. The models shows poor or nil performance in expressing real time situations and in providing the lower level details of user context like personal factors (role, mood, interest, activity, etc) and social factors (democratic, social influence, dominance, social events, geographic, culture, etc). The graphical models like ontology use very few notations to express all situations which make the user understandability very poor and complex. This necessitates the need of a model which is more expressive and easy to understand the user context from the perspective of end user and designer.

In this research work, the context entity model is proposed to represent logical and physical structural aspects of context, for a given entity like user. A set of dedicated

graphical notations for variety of context entities and their attributes are used to improve the completeness, expressiveness and understandability.

Research Issue 2: **Conflict Resolution in Context Aware Computing**.

Conflicts arise, when multiple users try to access or try to have a control on an application. Context aware applications are usually associated with one or more users competing for availing one or more multiple services. This necessitates the system to resolve the conflict, to improve the satisfaction level of the user. Conflict resolution is, conceptualized as the methods and processes, involved in decreasing the degree of disagreement or discomfort and hence increasing the level of satisfaction.

Currently the recommender systems resolves conflict using the content boosted collaborative techniques which makes use of user rating and group rating. The methods used are not context aware. Conflict varies from context to context. In addition to personalization and socialization, the recommender systems must be user context aware in order to resolve the conflict more, meaningfully. Hence there is a need of the context oriented conflict resolving system.

In this research work a series of algorithms are proposed to resolve conflict, which are context aware content boosted collaborative in nature. The proposed algorithms attempts to resolve the conflict by considering the user oriented context attributes like location, time, goal, environmental, physical, personal and social.

4. Modeling User Context

The chapter presents a context model, proposed in the research work. The model is designed to represent the static, external, structural and data aspects of a context aware system. The goal of the proposed model is, to express the *user context* effectively and to improve the understandability of *user context* from the *end user perspective*. In addition the proposed context model is used to design and develop context aware applications like Context Aware TV and Context Aware Mobile.

Publications of Research Work based on the research issue Modeling User Context

1. A Book titled, "A Novel Approach To Model User Context for Context Aware Applications", is published by LAP LAMBERT Academic Publishing house, Germany, https://www.lap-publishing.com/,ISBN:978-3- 8484-4900-2,April-2012.

2. A paper titled, "A Tool for developing activity –based application", is published in IEEE Pervasive Computing Magazine, volume = {7}, number = {2}, ISSN = {1536-1268}, year = {2008}, pages = {58-61}, publisher = {IEEE Computer Society}, address = {Los Alamitos, CA, USA}, WIP paper. April/ June2008, doi: http://doi.ieeecomputersociety.org/10.1109/MPRV.2008.25 (Impact Factor 2.293) (IEEE-Pervasive-Computing-Magazine).

3. A paper titled, "Modeling User Context for Interactive Context Aware TV", is published in the Proceedings of "2010 IEEE International Conference on Computational Intelligence and Computing Research", Dec 28 -29, 2010 organized by Tamilnadu College of Engineering, Coimbatore, India. E-ISBN: 978-1-4244-5967-4, Print–ISBN: 978-1-4244-5965-0, DOI: 10.1109/ICCIC. 2010.5705881.

4. A paper titled, " Modeling of User Preferences in Single and Multiuser Context Aware Environments for Interactive Context Aware TV", is published in International Journal Of Information Technology And Information Engineering, ISSN:0974 -4959 ,IJITIE ,January 2011 to March 2011,Spring Edition 2011,PP[41-52] .Volume 01 ,Issue No01,@Scientific Engineering Research Corporation, http://serc.org.in.,URL: http://www.serc.org.in/admin/pdffiles/7-VOL-01-IJITIE.pdf.

5. A paper titled, "Static Context Model and Metrics for Assessing the Completeness and Understandability of Static Context Model",is published in the refereed international IUP Journal of Computer Sciences, Vol VI,No-3,pp:[35-70]July-2012,ISSN:0973-9904,www.iupindia.in.
URL:1.http://www.iupindia.in/1207/Computer%20Sciences/Static_Context_Model_and_Metrics.html
2.http://www.iupindia.in/1207/Computer%20Sciences/Computer_Sciences.asp.

6. A paper titled, "Design and Implementation of Prototyping Simulator of Context Aware Applications",is published in the refereed international IUP Journal of Computer Sciences,Vol VI No 4, pp [7-34], October 2012,ISSN 09773-9904,www.iupindia.in., URL:http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2181823.

7. A paper titled, "Design and Implementation Of Reusable Components for Context Aware Rapid Application Development Toolkit", is published in International Journal On Computer Engineering And Information Technology, ISSN 0974 -2034, Jan /Feb -2010, Volume 12 ,No17,Pg.5-9. , @Scientific Engineering Research-Corporation, http:/serc.org.in. URL:http://www.serc.org.in/admin /pdffiles/ V12-2.pdf.

8. A paper titled, "Context Aware Rapid Application Development Simulator Toolkit for Ubiquitous Computing", is published in International Journal on Computer Engineering and Information Technology (IJCEIT) ISSN 0974 -2034. , @Scientific Engineering Research Corporation, URL: http://www.serc.org.in /admin/pdffiles/1-VOL-22-IJCEIT.pdf.

4.1 Preliminaries: In this section the meaning of user context and types of user context is described**:**

4.1.1 User Context: It is defined as**:** "Any information that can be used to characterize the situation of user**".** User context is a derived context and it is derived from the following categories of primitive contexts**:**

1. **Environmental** = {Users**#,** Light Intensity**,** Sound Level**,** Temperature**,** Devices**,** Sensors**,** Resources**,** Services**,** etc.}
2. **Social /Role** = {Father**,** Mother**,** Son **,** Aunt **,** Uncle **,**etc }
3. **Personal** = { Age , Expertise ,Weight ,Interest}
4. **Emotional/Mood** = {Normal, Excited ,Depressed, etc}
5. **Physical Posture** = { Sitting ,Standing , Running ,Fall etc }
6. **Physical Health** = {Normal, BP , Sugar,etc }
7. **Activity** = {Eating , Watching TV , Reading ,etc}
8. **Location** = {Living Room}
9. **Temporal** = { Date , Day ,Time }
10. **Service = {** Service provided by different context aware devices**}**

4.1.2 Categories of User Context: Depending on the number of users participating in particular situation user context is categorized into two categories**: 1**.Single user Context and **2.** Multiuser Context

4.1.2.1 Single User Context: The context which describes the situation of single user**.** Example**: "**Bob is watching TV in the Living Room in Relax Mood during late night**"**.

4.1.2.2 Multiuser Context: The context which describes the situation of multiuser. Example: **"**Family members Watching TV during late night**"** .

4.1.3: Context as a Set of Attributes: In this thesis**,** context is represented as a set of attributes which describes the entity and its situation**.**

i.e Context**=** {entity**,** situation}

Here entity is the set of attributes required to describe the entity with respect to the context under consideration which is given by

Entity = {Context_Id**,** Context_Category**,** Entity/List of Entities} .

The situation of a given entity is a set formed by union of all sets containing the values for each categories of primitive context and is represented as follows**:**

Situation = {Environmental Context**,** Personal Context**,** Task Context**,**
Social Context**,** Spatio-Temporal**,** ------}

. i.e, **Situation =** $\cup_{i=1}^{i=n} \boldsymbol{PC_i}\ \forall \mathbf{PC_i} \neq NULL$ ----------(**4.1.3.A**)

Whereas **PC,** represents the categories of primitive contexts like Environmental, Personal**,** Task**,** Social and Spatio-Temporal and $\mathbf{PC_i}$ denotes i^{th} primitive context**.** Each primitive context in turn is a union of all **Context Atoms (CA)** that when aggregated gives the collective information of primitive context**.** For example the primitive environmental context is the union of all its context atoms say light**,** users**,** weather**,** temperature**,** etc**.,** and respective attributes**.**

$$\mathbf{PC_i} = \cup_{j=1}^{j=m} \boldsymbol{CA_j}\ (\boldsymbol{pc_i}, \boldsymbol{name_j}, \boldsymbol{V_j})\ \ \forall \mathbf{V_j} \neq NULL; \text{ ----------(4.1.3.B)}$$

In which $\boldsymbol{CA_j}$ denotes the j^{th} atom of PC_i, $name_j$ denotes the name of the atom and V_j denotes the Value/State of the atom**.**

Equations (4.1.3.A) and (4.1.3.B) can be combined and the situation ($\boldsymbol{S_n}$) can be redefined as

$$\boldsymbol{Sn} = \cup_{i=1}^{i=n} \left(\cup_{j=1}^{j=m} \boldsymbol{CA_j}\ (\boldsymbol{pc_i}, \boldsymbol{name_j}, \boldsymbol{V_j}) \right)$$

$$\forall \mathbf{PC_i} \neq NULL \quad \& \quad \forall \mathbf{V_j} \neq NULL; \text{ ---------- (4.1.3.C)}$$

Fig3 illustrates how one can represent user context in terms of attributes of primitive context and context atoms**.**

Context ID	***Context Category***	***Entity / List Of Entities***
Environmental (PC_1)		*CA_1(Environmental)*
		CA_2(Environmental)

		CA_{m1}(Environmental)
Social (PC_2)		*CA_1(Social)*
		CA_2(Social)

		CAm_2(Social)
Personal(PC_3)		*CA_1(Personal)*
		CA_2(Personal)

		CAm_3(Personal)
Temporal(PC_4)		*CA1(Temporal)*
		CA2(Temporal)

		CAm4(Temporal)
Service (PC_5)		*CA1(Service)*
		CA2(Service)

		CAm5(Service)
----------(PC_n)		*--CAmn*

Fig3: Representation of User Context in terms of Attributes of Primitive Context.

Following section gives two real-time examples of representation of context of entities using Primitive Context Attributes**.**

Example1: Fig4 illustrates the representation of context of father and mother located in living room, using primitive context attributes and the respective context atoms.

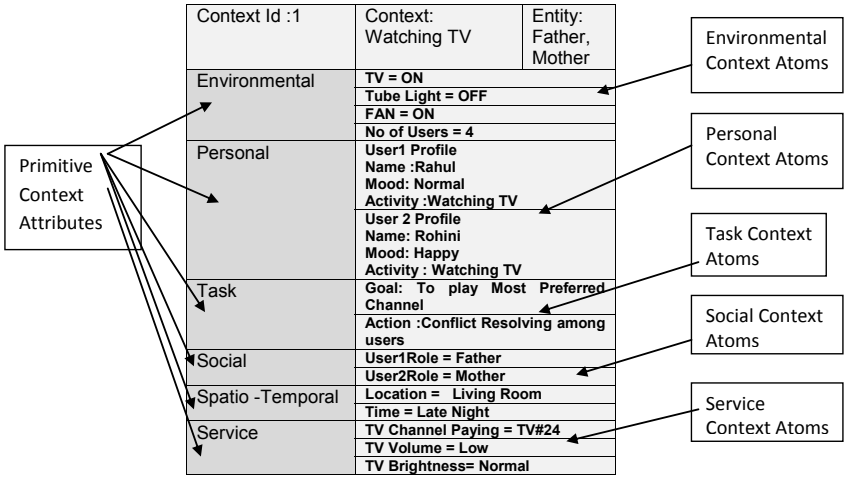


Fig4: Context of Father and Mother

Example2: Fig5 illustrates the representation of context of mobile.

Context ID	***Device Context***	***Mobile***
Environmental	*Temperature = High* *Light Intensity = High* *# o f Mobiles nearby =05* *# of Wifi/Bluetooth devices=10* *Signal Strength : High*	
Social	*User Role =Professor*	
Personal	*Make=Samsung Galaxy ACE*	
	Battery Level :Full	
	Mobile #: 9480123526	
	MAC Address :	
	Owner: Rahul	
Emotional	*Owners mood : Normal*	
Physical	*Users Health= Good* *User Physical Posture = Sitting*	
Activity	*Users Activity= Studying*	
Location	*Library, Reading Room*	
Temporal	*Evening*	
Service	*Mode: Silent* *Call Status : Allow only Emergency Call*	

Fig5: Context of Mobile (DEVICE/SENSOR)

4.2 Proposed Modeling of User Context

The models are graphical representations used to describe the entities, relationships, events, actions, computing processes, the problems to be solved and the systems that are to be developed. The models with graphical notations and symbols are more understandable than the natural languages. Modeling context is a fundamental step for the design and development of context aware systems. The context modeling is useful for understanding context aware problems, designing programs and databases.

The proposed modeling of user context is a graphical representation of user context in terms of attributes and relationships of context entities like users, sensors and devices. The model is designed by integrating the concepts of ontology, key value and ER models. The model is static and it provides an instance or snapshot of user context as captured by the context aware system. The main usage of the model is to provide a logical and physical structure in designing context aware systems. The goal of the proposed model is to construct a user context model, to capture those concepts from the real world that are important to design and develop user context aware applications like Context Aware TV, Context Aware Mobile Phone, Context Aware Meeting Room, etc.

The basic concepts used to present the proposed modeling of user context are described below:

Entity: Any object which is required to describe the situation of other object. For example in order to describe the context of user one may need different entities like sensors and devices.

Context Entity: The object of interest (entity) whose situation has to be described. Example: Context of mobile, User context.

Multiple Entities context: The group of context entities, whose collective situation has to be described. Some of the examples to list are: 1. "context of family" 2. "context of 2nd semester B division students" 3."the context of five computers present in the browsing centre" 4. "context of all devices installed in class room".

Context Attributes: A set of attributes which can be used to describe the situation of context entity at a given point of time. Each attribute of an entity can assume values from a set of permitted values. Attribute may be simple (primitive/primary) or derived (secondary) attributes. A simple attributes are the atomic attributes like time, location, activity, mood etc., which when concatenated meaningfully, generates secondary context attributes.

Simple attributes may be single valued or composite valued. For example location can take the single value like class room or it can take the composite value like classroom, dept of cse, sdmcet.

Derived attributes are always composite valued. For example the user context: "Raju is studying in reading room during late night" is derived by concatenating the primitive attributes like personal, activity, location and time meaningfully.

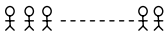
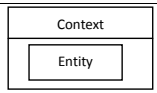
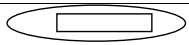
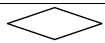
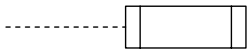
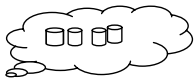
Table5 below illustrates some of the example for simple and derived context attributes.

Table5: Categories of Context Attributes

Context Attribute Type	Example Context	Components	Examples
Simple (Composite or Single Valued)	Temporal	Date, Day, Time.	23rd March Saturday Class Hours.
	Location	Indoor, Outdoor.	Meeting Room, College Campus.
	Activity	Events or Task.	Meeting, Playing.
	Mood	Emotional state	Normal
	Personal	Name, Address, Age, Sex, Role, etc.	Rohan, Male, #123, SDM, Dharwad, Student.
Derived (Composite Valued)	Single User	User Personal details, User Mood, User Activity, Time ,etc.	Rohan, son of Ramu is watching TV in living room.
	Multi user	Personal details, mood, activity, location, conflict, time etc., of all the users in a group.	Family members watching TV during late night.

4.2.1 Context Entity Attributes Relationship Diagram (CEAR – Diagram) : The proposed model is represented graphically using context entity attributes relationship (CEAR) diagram. The diagram is a graphical representation of association between the context entities and attributes. The diagram is an extension of ER diagram meant specifically for context data generated in context aware environment. The graphical notation / symbols used to draw CEAR – Diagram is listed in the table6.

Table6: Graphical /Symbolic Notations used in CEAR Diagram

Sl.NO	Graphical/Symbolic Notation	Meaning
1		Single User
2		Multiple - users
3		Sensor
4		Device
5		Entity - user / sensor / device
6		The Context of a given entity
7		Simple Context Attribute
8		Derived Context Attribute
9		Composite Context Attribute
10		Link the attributes, relationship and entities.
11		Capture
12		Retrieve / Get value
13		Submit and Retrieve
14		Relationships
15		Aggregator used to generate the composite context attribute from the multiple sensors.
16		Call a method to resolve conflict
17		Data base inside Cloud or Internet
18		Data bases in the system like mobile ,laptop ,desktop etc.

Example: Figure6 illustrates the CEAR diagram to represent context of user in study room using the graphical notations described in Table**6**

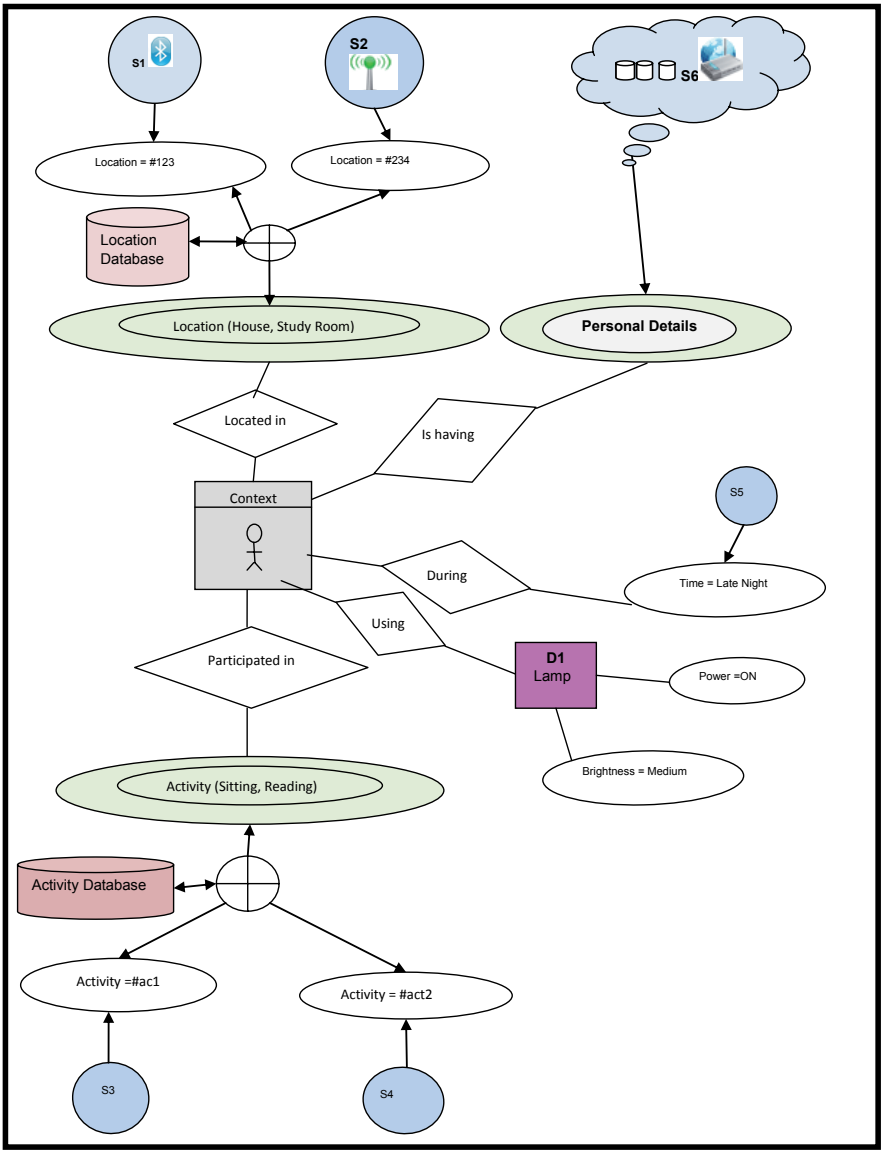


Fig6: CEAR Diagram to represent User Context in Study Room

The CEAR Diagram illustrated in Fig6 models the user context in study room. The model provides the overall logical and physical structure of context aware study room. The model can be used to design a context aware study room.

Physical Structure: The model expresses the physical structure of the context aware system including the details of sensors and devices used in the model and their functionalities. As prescribed by the model the user study room is comprised of four physical sensors, one device and two databases.

Table7: Physical Structure expressed in the CEAR Diagram

Physical Component	Functional Details
Sensor S1	Bluetooth Tag to identify the Sub location id.
Sensor S2	Wi-Fi Access Point to identify the Main Location id.
Sensor S3	Activity Sensor to return the activity like physical posture id of the user .
Sensor S4	Activity sensor to the return the social activity id of the user.
Sensor S5	Time sensor which returns the current time of the context.
Sensor S6	Logical Sensor in the form of database stored in the Cloud or internet which provides the necessary details through internet searching.
Device D1	A device say lamp which can provide a service like power (On/OFF) and Brightness (High, Medium, low or Nil).
Location Database	A logical sensor which returns the name of location for each location id.
Activity Database	A logical sensor which returns the name of activity for each activity id.

Logical Structure: The CEAR diagram expresses graphically the overall logical structure of user context at a point of time. It expresses the situation of a given context entity (say user) by associating its relationship with attributes of entities.
For example, the user location context is expressed by associating the relationship (*located in*) between the location attribute and user. Location attribute is a composite attribute which is obtained by integrating the attributes like sub location and main location. Table8 illustrates the different primitive and composite context expressed in the fig6.

Table8: Logical Structure Expressed in the CEAR diagram

User Context Type	Relationship	Instance of Attribute
Location	located in	(House, Study Room, Chair)
Personal	having	Personal details (Name: BEL, Role: Son, Age:15, Sex:Male, Priority, Medium, UID:12356)
Time	During	Late Night
Device	using	Power=ON, Brightness= Medium
Activity	Participated in	(Sitting ,Reading)

The complete contextual information represented by CEAR Diagram in figure6 is given in the table9 below:

Table9 : The context information expressed in the CEAR diagram (Figure6)

Legend	***Details of Contextual information expressed***
Context Entity	• **The intention of the diagram is to express the context of user (context entity).**
Environmental	• **The ambient is study room in a given house.** • **The number of user present is one .** • **The ambient is filled with six sensors and one device.** • **The sensors used are location sensor(Bluetooth Tag, WIFI Access Point),Logical Sensors(Cloud Database, Location Database, Activity Database) ,Activity Sensors (two in number) and Time Sensor.** • **The device is LAMP and is switched on with status :Power=ON and Brightness= Medium.**
Personal	• **The user is a member of family and having personal details: role=son, age=15, sex=male, priority =medium and uid = 12356.**
Emotional/Mood	• **Not Available**
Social /Role	• **User is a member of some family with role = son,age=15 and priority = medium.**
Physical Posture	• **User is sitting**
Physical Health	• **Not Available**
Activity	• **The user is sitting and Reading.**
Location	• **The user is situated in Study Room of a given House**
Temporal	• **The time of activity is Late night.**

Summary of User Context description expressed in CEAR diagram (Fig6):

The context represented is a single user context. The user is having the following personal details:

Name = BEL,
Role = Son,
Age = 15,
Sex = Male,
Priority = Medium and
UID = 12356.

The user is located in the study room of his house. The lamp is switched ON with medium Brightness. User is sitting and studying during late night.

4.2.2 Experimental and Result Analysis: The analysis of CEAR diagram was made in terms of Completeness and Understandability.

A. **Completeness** can be defined as the amount of information that the CEAR diagram provides, to express the current context of a given entity. It is measured in terms of percentage of information that the diagram can provide or expresses about the current context of a given entity. The amount of the information provided by each

diagram is measured by performing cross checking in the form of predefined queries related to the different categories of primitive contexts. For each context representation a set of queries was evaluated. Table10 lists some of the probable sample queries with respect to the different primitive contexts that can be used in order to evaluate the completeness of the context representation using CEAR diagram.

Table10: Typical Context Queries

Legend	***Some of the Typical Queries (But not limited)***
Context Entity	**Whether the CEAR diagram contains the notation to represent the entity whose context has to be determined ?What is the Goal or intention of the CEAR diagram?**
Environmental	**How many users are present? What is the light intensity? What is the current temperature?** **How many devices are there in the ambient space? How many sensors are present in the given ambient space? What is the power status of devices and sensors present in the contextual ambient space?etc.**
Personal	**What is the user name? What is the user identity? What is the user employee id?** **What is the user social security number id ?What is the user profile?** **What are the user favorite items? What are the user preferences?** **What is the priority of the user? What are user ratings for the given item?** **What are the strengths? What is the weakness? What is his/her intention?** **What is his goal? etc.**
Emotional/Mood	**What is the current mood? (Normal , Excited ,Abnormal, etc)** **Whether the user's mood effect is positive? Whether the user's mood effect is negative?etc.**
Social /Role	**What is the designation of the user in the organization?** **What is the role of user in the household?** **What is the social status of the user?** **What is the priority of the user based on his social role?etc.**
Physical Posture	**What is the physical posture of the user?** **Sitting or Standing or Walking or Running or Sleeping or Taking Rest. Etc.,**
Physical Health	**What is the physical health condition? Normal or Abnormal?** **High BP , Low BP , Sugar etc**
Activity	**What is the current activity of the user involved?** **Meeting / Delivering Lecture / Group Discussion / Playing /Watching TV /Taking Food / Sleeping /Taking Rest /Reading / etc.,**
Location	**To Which location the user belongs.** **Main Location: College Campus, Railway Station, Bus Stand, House, Outdoor (On Road).** **Sub Location: Meeting Room, Class Room , Conference Hall ,CSE Dept.** **Interior location: Chair , Sofa set , etc.,**
Temporal	**What is the current time?** **Morning, Afternoon, Evening, Night, Early Morning, etc..**

The completeness is measured by determining the amount of information the CEAR diagram provides related to context.

C(CEAR) = 1/m $\sum_{=1}^{n} Wi$, ----------(**4.2.2 .A.1)**

Whereas W_i is the weight assigned to each context categories. W_i is computed using the equation $W_i = Q_{awd}/Q_{req}$ ---------- (**4.2.2 .A.2)**

Whereas, Q_{awd} is the total number of questions answered by the diagram and Q_{req} is the total number of questions required to be answered

For example consider the CEAR Diagram in Fig6 . The complete contextual information expressed in the CEAR Diagram is listed below

Table11: Contextual Information represented in Fig6

Legend	***Contextual Information provided by the CEAR diagram based on the queries asked.***	***Percentage of the Completion***
Context Entity	***Q1:Whether the CEAR diagram contains the notation to represent the entity whose context has to be determined ?*** ***Ans: YES*** ***Q2: What is the Context Entity ?*** ***Ans: USER*** ***Q3: What is the intention of the CEAR Diagram ?*** ***Ans: To represent the context of user in the study room .***	***(3/3)*** ***100 %***
Environmental	***Q1:How many users are present?*** ***Ans:ONE*** ***Q2: What is the light intensity?*** ***Ans: Not Available*** ***Q3: What is the current temperature?*** ***Ans: Not Available*** ***Q4: Does the CEAR contains the complete Description of Ambient space?*** ***Ans: No*** ***Q5:How many devices are there in the ambient space?*** ***Ans:One*** ***Q6:How many sensors are present in the given ambient space?*** ***Ans:SIX*** ***Q7: Whether the environmental conditions are favorable for performing the task ?*** ***Ans: Not Available***	***(3/7)*** ***43%***
Personal	***Q1: Does the CEAR Diagram represents the complete personal details of the user*** ***Ans: YES*** ***Q3: What is the intention of the USer ?*** ***Ans: Not Available*** ***Q4: What is the Activity of the user ?*** ***Ans: Sitting and Reading*** ***Q5: Whether the user is student or house keep or employed ?*** ***Ans: Not Available***	***(3/5)*** ***60%***
Emotional/Mood	***Q1:What is the current mood of the user?*** ***Ans : Not Available*** ***Q2: Whether the mood is favorable to the activity studying?*** ***Ans: Not Available*** ***Q3: Whether the user's mood effect is negative?*** ***Ans : Not Available***	***(0/3)*** ***0 %***
Social /Role	***Q1:What is the role of user in the household?*** ***Ans: Son***	***(1/1)*** ***100 %***
Physical Posture	***Q1:What is the physical posture of the user?*** ***Ans: Sitting.***	***(1/1)*** ***100 %***
Physical Health	***Q1:What is the health condition of the user ?*** ***Ans: Not Available***	***(0/1)*** ***0 %***
Activity	***Q1:What is the current activity of the user involved?*** ***Ans: Reading***	***(1/1)*** ***100%***
Location	***Q1:To Which location the user belongs.*** ***Ans: House ,StudyRoom***	***(1/1)*** ***100%***
Temporal	***Q1:What is the current time?*** ***Ans: Late Night***	***(1/1)*** ***100%***
	Aggregate Percentage of Completion	***(17/24)*** ***70.833%***

B.Understandability can be defined as the ability to easily understand the current context of any entity under interest using the CEAR diagram**.** To get a proper assessment of the understandability of the CEAR diagram**,** research work did a survey of 100 computer engineering students on the understandability of the CEAR

diagram in the college campus. A set of 20 CEAR diagrams representing different user context was considered for experimental purpose. A set of 20 diagrams and questions about the understandability of the representation was handed over to each student. They were asked to answer the questions on a scale based on the following understandability linguistic labels:

1. Extremely Difficult to understand
2. Very difficult to understand
3. A bit difficult to understand
4. Neither difficult nor easy to understand
5. Understandable
6. Quite easy to understand
7. Very easy to understand

From the survey of 100 students about 45 students agreed that the model is quite easy to understand, 30 students found that the model is very easy to understand,15 students found that model was understandable and 10 students found that the model is understandable after getting enough explanation.

From the graph (Fig7) it is evident that the proposed CEAR diagram which is used to model the user context provides very good support towards understandability. Most of the students felt that one can easily represent the user context using CEAR diagram after performing enough practice on the graphical notations.

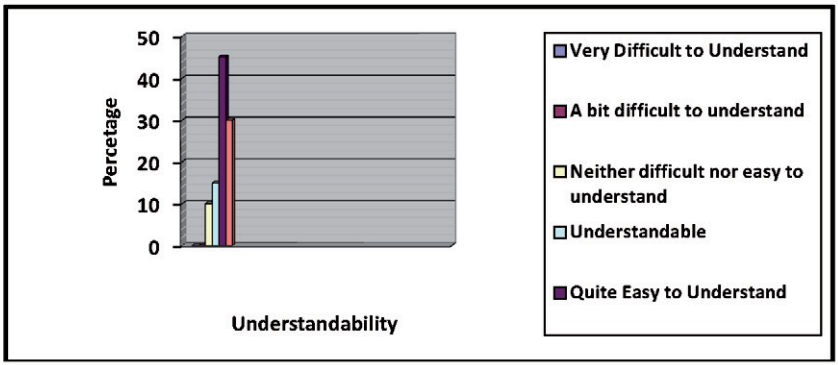


Fig7 : Percentage of the Understandability of the CEAR modeling.

4.2.3 Comparison of the Proposed Model with Existing Models: The model was compared with related works in terms of following features:

- **Expressiveness:** The model is capable to express maximum information within the representation. In order to improve the expressiveness the model has used the domain specific graphical notations. For example it makes use of different unique notations for user, sensor and devices and also for expressing the relationship between them. The model is also capable to express the information like derived information, aggregated information and the sources of information.
- **Simplicity**: The model makes use of ontological notations which users are aware about them in their everyday life. For example the notations used for Bluetooth, Wifi, databases, cloud, etc are familiar to all the current generation students. Most of the notations are also taken from the set of notations used for drawing ER Diagram.
- **Richness and Quality of information:** Since the model makes use different notations for all entities (user, sensor and devices) and relationship, it naturally improves the richness and quality of information. For example to extract the location information the model makes use of different sensors like Bluetooth (for indoor location), Wi-Fi (for indoor location), GPS (for outdoor location), etc.
- **Level of Formality:** The model is governed by need based rules and associations among the entities. The level of formality is user friendly, the user can define and associate his own adhoc based rules.
- **Application to existing environments**: Since the model is context aware domain specific. It is applicable to existing context aware environments as well as future environments. For example one can use the model to explain the existing context aware systems (like smart mobile, smart TV) and to design the future environments (like smart home, car, etc.).
- **Aggregation Support:** The model has good support towards aggregation. One can represent the aggregation of data from different sources of information (like sensors) and generate a new meaningful data. For example,

one can aggregate the data from sensors like location, activity, time, user identity, etc., and generate a meaningful user context.

In addition to the above features the model provides good support towards completeness and understandability as discussed in the earlier section. Table12 illustrates the comparison of the proposed model with the existing models with respect to the different features specified in the table.

Table12: Comparison of the Proposed Model with Existing Models

Feature	KVM	MM	OnM	OOM	LBM	Proposed Model
Model Category	**N**	**N**	**N**	**N**	**N**	**H**
Model Expressiveness	≤	<	++	+	<	++
Simplicity	++	++	++	+	<	++
Richness and Quality of information	≤	+	+	+	≤	++
Level of Formality (for)	≤	+	++	+	++	+
Applicability to existing environments (app)	**NA**	++	++	+	≤	++
Aggregation Support	≤	≤	+	++	+	++
Understandability	+	+	+	+	<	++
Completeness	≤	+	+	+	<	+

≤ : No /Limited , < : low , + : Partial /Medium /Average ++ : Complete/ High/ Good , NA : Not Applicable , N: Natural H: Hybrid , U:Unknown ,
KVM : Key Value Modeling ,MM : Mark Up Modeling , OnM ; Ontology Modeling ,OOM : Object Oriented Modeling , LBM : Logic based Modeling .

5. The Generic Architecture of Context Aware Systems

The research work presented in this thesis proposes a generic layered architecture for designing context aware applications as illustrated in the Fig8. The architecture can be used for designing the context aware applications like context aware TV, Context Aware Mobile, Smart Meeting Room, etc. The proposed general architecture consists of five layers described below:

1. User Environmental Space: It is a bounded space where in the user participates in different activities. The space may be indoor or outdoor. Some of the examples for indoor environmental spaces are living room, kitchen, bed room, meeting room, class room, seminar hall, library hall, etc., and similarly some of the examples for outdoor environmental spaces are bus stand, railway station, etc.

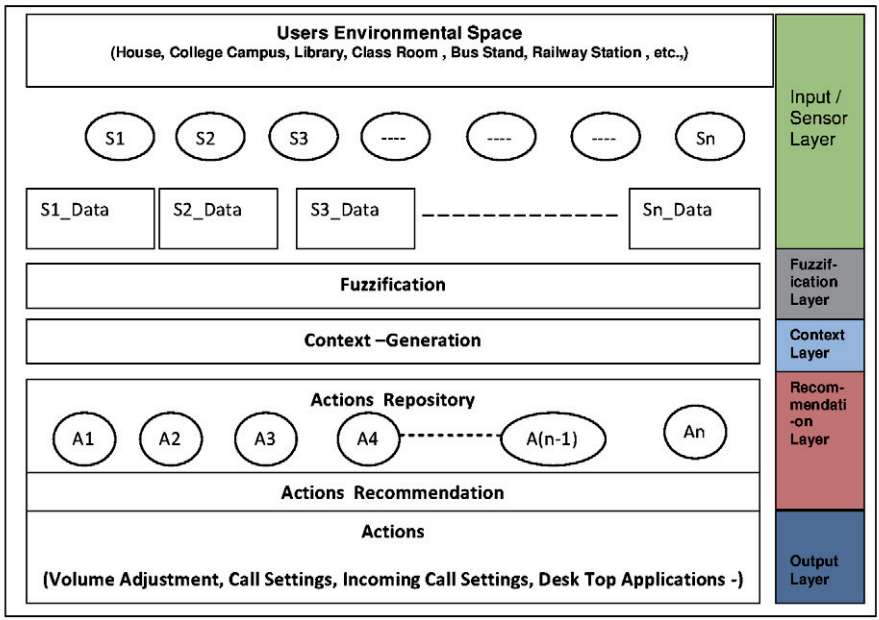


Fig8: Layered Architecture of generic Context Aware System

2.Sensor Layer: The sensor layer which is saturated with sensors like temperature sensors, time sensor, activity sensor, mood sensor, etc., provides a raw sensor data

to fuzzy layer for fuzzification.The sensor data are dynamic and represents the changes in environment whenever some changes through events or actions changes occurs in the environmental space.

3. Fuzzification Layer: The Conversion of Crisp input (discrete or continuous) into fuzzy values represented by linguistic terms using membership functions called fuzzification. In the fuzzification layer, sensors value will be fuzzified into linguistic terms using respective membership functions like triangular, trapezoidal, singleton and Gaussian. Some of the linguistic terms used in fuzzification are low, very low, normal, cold, very cold, hot, very hot, warm, near, far, exactly, early, near, far etc. The layer provides a fuzzified sensor value to the context layer to generate context.
Users are not sensitive to crisp values, but they are sensitive to fuzzy values. For example users are not sensitive if the temperature changes from 20 degree celsius to 20.1 degree celsius. But user can feel the change of temperature from cold to normal or normal to hot.
Also, the dynamic nature of context aware systems results in exponential increase of the knowledge base regularly. Fuzzification reduces the size of knowledge base and hence increases the performance in terms of memory and time. Table13 gives the details about the membership functions and linguistic terms used for different context attributes in the research work.

Table13: Fuzzy information of primitive context related to user.

Context Attributes	Fuzzy Set Values	Fuzzy Linguistic terms	Fuzzy Membership Function
Location	Indoor Location : Living Room, Class Room, Meeting Room,SofaSet, Chair1, Chair2, Floor, Table1, Table2, Entrance, Dining Table,etc. Outdoor Location : Corridor, Campus Ground, Play Ground, Bust Stand, Market Place,etc.	low , fair , good, excellent	Trapezoidal
Time	AM1, AM2, ------AM12, PM1------PM12, Early Morning, Morning, Afternoon, Forenoon, Evening, Night, Late Night.	Yes ,No	Singleton Function
Weekday	Monday ,Tuesday, Wednesday ,Thursday , Friday, Saturday , Sunday , Holiday, Working Day.	Yes ,No	Singleton Function
Physical	Fall , Normal	Yes, No	Singleton Function
Temperature	Current temperature in degree Celsius	Very Cold, Cold, Warm, Hot, Very Hot	Trapezoidal function
Activity	Standing ,Sitting , Running ,Walking , Jogging , Eating , Talking ,Resting ,Sleeping ,Playing ,Reading ,Exercise.	True / False	Singleton
Mood	Happy, Normal, Relax, Cheerful, Depressed, Excited, Disturbed, Comfort, Angry, Disturbed.	True /False	Singleton

4. Context Layer: In this layer aggregation of fuzzified linguistic terms takes place using logical AND operation. The aggregated context provides complete meaningful information about the situation of a given entity. For example the context of Raju is said to be sleeping if,

"***(Time==Night_Hours) && (User_Location==BedRoom) && (BedRoom_Light_Level==Dark) && (BedRoom_Curtain_Status==CLOSED)&&(User_Activity==Resting)&& (User_Physical_Posture == Sleeping) ".***

5. Recommendation Layer: In this layer context based services will be recommended. Conflict resolution will be resolved, if any, in this layer before recommending the services. It includes the repository of actions in the form of functions and APIs.

6. Output Layer: This layer is saturated with devices and includes the environment in total, where in the context aware systems are situated. The actions will be executed using appropriate devices.

6. Conflict Resolution and Service Recommendation in Context Aware Computing based Applications

Conflict resolution in context-aware computing is getting more significant attention from researchers as ubiquitous computing environments take into account multiple users, multiple devices, multiple sensors and multiple applications. In multi-user ubiquitous computing environments, conflicts among user's contexts need to be detected and resolved.

In this chapter, a set of algorithms to resolve conflict is introduced. The algorithms can be embedded in different context aware applications like context aware devices (say TV, Mobile, AC and Fan) and Context Aware Ambient (like Meeting Room, Living Room, Restaurant, Coffee Shop, etc).

Publications of Research Work based on the research issue Conflict Resolution and Service Recommendation

[1] A paper titled, "*Conflict Resolution in multiuser context aware environment*", is published in IEEE Pervasive Computing Magazine, volume = {7}, number = {2}, ISSN = {1536-1268}, year = {2008}, pages = {58-61}, publisher = {IEEE Computer Society}, address = {Los Alamitos, CA, USA}, WIP paper. April /June 2008, doi:http://doi.ieeecomputersociety.org/10.1109/MPRV.2008.25 (Impact Factor 2.293) (IEEE-Pervasive-Computing-Magazine).URL:https://docs.google.com/file/d/0B7pFWDvbA3UOYjFkZDdhNTQtZGZkYy00NGRmLTgyOWUtZmE1NTQ4MTdjYTQx/edit?authkey=CIv7-s0I&hl=en&pli=1.

[2] A paper titled, "*Conflict Resolving Algorithms to Resolve Conflict in Multi-user Context Aware Environments*," is published in Proceedings of IEEE *International Conference on Advanced Computing.* Issue Date: 6-7 March 2009 On page(s): 202 - 208 Location: Patiala, Punjab Print ISBN: 978-1-4244-2927-1 INSPEC Accession Number: 10556624
Digital Object Identifier: http://dx.doi.org/10.1109/IADCC.2009.4809007

[3] A paper titled, " *Interactive Democratic Group Preference Algorithm For Interactive Context Aware TV* " , is published in proceedings of *2010 IEEE International Conference On Computational Intelligence And Computing Research,* Dec 28 -29 ,2010 organized by Tamilnadu College Of Engineering ,Coimbatore, India. E-ISBN: 978-1-4244-5967-4,Print-ISBN: 978-1-4244-5965-0.Digital Object Identifier: http://dx.doi.org/10.1109/ICCIC.2010.5705880

[4] A paper titled, " *Modeling Of User Preferences in Single And Multiuser Context Aware Environments For Interactive Context Aware TV* " is published in *International Journal Of Information Technology And Information Engineering*, ISSN:0974 -4959 ,IJITIE ,January 2011 to March 2011,Spring Edition 2011,PP[41-52] .Volume 01 ,Issue No01 ,@Scientific Engineering Research-Corporation,http:/serc.org.in.*(International-Journal)*,
URL: http://www. serc.org.in/admin/pdffiles/7-VOL-01-IJITIE.pdf.

[5] A paper titled, "*Family Aware TV Program and Settings Recommender*", is published in International Journal of Computer Applications (IJCA) 29(4):1-18, September 2011. Published by Foundation of Computer Science, New York, USA. (ISSN: 0975 – 8887) ", Volume 29– No.4, September 2011, Article N0:1 pp [1-18],doi:10.5120/3556-4889, (Impact Factor 0.835)
URL:http://www.ijcaonline.org/archives/ volume29 /number4 /3556-4889.

[6] A paper titled, "*Design and Implementation of User Context aware Recommendation Engine for Mobile using Bayesian Network, Fuzzy Logic and Rule Base* ",is published in International Journal of Computer Applications (IJCA) 40(3):47-63, February 2012. Published by Foundation of Computer Science, New York, USA. (ISSN: 0975 – 8887) ", Volume 40– No.3,pp [47-63],doi: http://dx.doi.org/10.5120/5028-7176, (Impact Factor 0.835)
URL:http://www.ijcaonline.org/archives/ volume 40 / number3 /5028-7176.

[7] A paper titled, "*Rough Set Theory based User Aware TV Program and Settings Recommender*", is published in International Journal of Advanced Pervasive and Ubiquitous Computing Applications, an official publication of the information resources management association ,April –June 2012 ,Vol4 ,No2 ,IGI-Global Publishing house, pp[48-64],WWW.IGI-Global.com,ISSN1937-965X,eISSN-1937-9668,http://www.igi-global.com/ijapuc,DOI:http://dx.doi.org/10.4018/ japuc.2012040105,
URL:http://www.igi-global.com/article/rough-set-theory-based-user/71885

[8] A paper titled, "*Algorithms to Resolve Conflict in Multiuser Context Aware Ubiquitous Environment*", is published in International Journal of Advanced Pervasive and Ubiquitous Computing Applications, an official publication of the information resources management association ,July –September 2012 ,Vol4 ,No3 ,IGI-Global Publishing house , pp[42-62] , WWW.IGI-Global.com,ISSN 1937-965X,eISSN:1937-9668,http://www.igi-global.com/ijapuc, DOI: http://dx.doi.org/10.4018/japuc.2012070103
URL:http://www.igi-global.com/article/algorithms-resolve-conflict-multiuser-context /73651

[9] A paper titled, *"Design of Context Aware Recommendation Engine for Cell Phone using Bayesian Network, Fuzzy Logic and Rough Set Theory*" got selected for the publication in IGI-Global, International Journal of Advanced Pervasive and Ubiquitous Computing Applications, Volume 4 Issu4 (October – December 2012).

In the presented research work, the usage of the algorithms is demonstrated in designing the applications like Context Aware TV and Context Aware Mobile. The algorithms discussed make use of different AI tools like Probability, Fuzzy Logic, Bayesian Network and Rough set theory. In addition the algorithms utilize various factors like social, personal and environmental. The motto of the research work is to enable context aware applications to offer socialized and personalized services to single user or multiple users by resolving service conflicts among users.

6.1 Conflict in Context Aware Ubicomp Environment

Ubiquitous environment is generally saturated by set of devices which will provide a varied set of services to user. Context aware recommendation engine experiences a conflict situation whenever the services provided by the system leads to disagreement or discomfort or dissatisfaction in user. The research work presented in this thesis considers only such conflict that arises between user and services offered by the context aware applications.

Conflict in context aware ubicomp environment is defined as the degree of disagreement or discomfort between user's interests with respect to the services recommended by the context aware application. Conflict may between the individual user and ***n*** number of services provided by the system or it may be between the ***m*** number of users and ***n*** number of services. Accordingly the conflict in context aware ubicomp environment is categorized into two types:

1. **Single user *versus* multiple services:** In this type the conflict is between different services and single user. Here the conflict arises due to the dissatisfaction between the user and services offered by applications. Some of the examples to list are:

- Conflict between the mood of the user and different TV Channel programs.
- Conflict between the social situation of the user and services offered by the mobile phone.
- Conflict between the personal situation of the user and services offered by the devices like AC, Mobile, etc.

2. Multiple users *versus* Single/Multiple services: In this type the conflict is between multiple users and single or multiple services. Here the conflict arises due to the dissatisfaction between users to have a feel or control of the services offered by applications. Some of the examples to list are:

- Conflict between different family members watching TV in living room to have a control on the TV.
- Conflict between groups of members conducting meeting in meeting Room with respect to the service offered by AC.
- Conflict between students attending class in the class room with respect to the service offered by Fan.

Reasons behind the conflict in context aware environment: If there are multiple users in a context aware environment, each one is capable to control and interact with services, conflict may occur. This happens when different users want to, explicitly have a control on the same service of a system at the same time. Typical reasons for conflict:

1. To have a control of the system
2. To interact with the system

6.2 Service Recommendation: Recommending the appropriate context based service is very important in context aware systems. The context may be single user context or multiuser context. The context may be with or without user conflict. If the context is associated with the users conflict the conflict has to be resolved first followed by service recommendation.

6.3: Algorithms to Resolve Conflict and Recommend Service

A set of algorithms to resolve conflict among users or services is proposed in this research work. The algorithms are designed by integrating the social, personal and democratic factors with Artificial Intelligence tools like fuzzy logic, fuzzy Bayesian probability and rough set theory. In addition the recommendation engine utilizes the contextual parameters like personal, social, temporal, activity, mood and schedule agendas to improve the satisfaction level of the user. The usage and analysis of the proposed algorithms are demonstrated in developing context aware applications like Context Aware TV and Context Aware Mobile Phone. The proposed algorithms are discussed under two categories:

1. Conflict Resolution and Service Recommendation in Context Aware Environment with Single User and Multiple Services
2. Conflict Resolution and Service Recommendation in Context Aware Environment with Multiple users and Single /Multiple Services.

6.3.1. Conflict Resolution and Service Recommendation in Context Aware Environment with Single User and Multiple Services.

Following algorithms are proposed for resolving conflict and recommend service in context aware environment with single user and multiple services.

1. Fuzzy Rule Based Algorithm. (FRBA)
2. Bayesian Probability Based Algorithm. (BPBA)
3. Fuzzy Decision Table Based Algorithm. (FDTBA)

6.3.1.1 Fuzzy Rule Based Algorithm (FRBA): The algorithm makes use of predefined fuzzy rules to resolve the conflict as soon as some conflict is detected. Some of the sample fuzzy rules (for student user) used for the context ware mobile system in the research work is illustrated in table14.

Table14: Example Fuzzy Rule Base

CONTEXT	RULE1	RULE2	RULE3	RULE4	RULE5	RULE6	-	-
Fall	No	No	No	Yes	No	No		
Location	Class Room	Class Room	Class Room	Class Room	Library	Admin Block		
Day	Working Day	Working Day	Working Day	Working Day	Working Day	Working Day		
Time	Class Hours	Class Hours	Class Hours	Class Hours	Free Hours	Free Hours		
Activity	Attending Class	Attending Class	Attending Class	Attending Class	Studying in Library	Standing		
Incoming Call	No Call	High Priority Call	Emergency Call	No Call	High Priority Call	No Call		
Temperature	Normal	Normal	Normal	Normal	Normal	Very Hot		
ACTIONS								
Profile	Silent	Silent	Vibrating	Alarming	Silent	General		
Volume	Zero	Zero	Zero	High	Zero	High		
Call Settings		Auto Answering Mode	Vibrating Alert	Auto Answering Mode	Vibrating Mode	Ringing Mode		
Messaging	No	Auto Status Message	Auto Status Message	Auto Status Message	Auto Status Message	Active		
Contacts	Hide	Hide	Hide	Display	Display	Display		
Log	Hide	Hide	Hide	Hide	Display	Display		
Settings	Hide	Hide	Hide	Hide	Display	Display		
Gallery	Hide	Hide	Hide	Hide	Display	Display		
Media Player	Hide	Hide	Hide	Hide	Hide	Display		
My Entertainment	Hide	Hide	Hide	Hide	Hide	Display		
My Shopping	Hide	Hide	Hide	Hide	Hide	Display		
Internet	Display	Display	Display	Display	Display	Display		
My Map	Display	Display	Display	Display	Display	Display		
My Context	Display	Display	Display	Display	Display	Display		
My Friends Search	Hide	Hide	Hide	Display	Display	Display		
Desktop Screen	Display	Display	Display	Display	Display	Display		
My notifications	Hide and Waiting Mode	Hide and Waiting Mode	Display about Emergency Call	Display	Hide and Waiting Mode	Display Adhoc services		
Other Applications	Hide	Hide	Hide	Hide	Hide	Display		

Whenever the student carries his mobile from outdoor to the class room, conflict arises between the student context and the services settings prevailing in the mobile at that moment of time. The mobile system detects the conflict as there will be change in the user context. The system records the current context (CC), with the help of its embedded sensors, and searches for the suitable rule in the rule base for which the conditional attributes will have the same value as that of current context attribute value. If found the system makes necessary settings according to the

values stored in the actions part of the rule. The following section discuses the working of the rule based conflict resolution and service recommendation in detail.
The fuzzy rule base is a knowledge base containing rules(R), conditions(C) and actions (A). Each rule is made up of conditions and actions. If conditions are satisfied then the actions get activated. The rules are build using fuzzy condition attributes and fuzzy action attributes. The fuzzy attributes are considered because humans are more sensitive to fuzzy attributes than the crisp attributes. The attributes in the rule base is sorted in the order of priority.

The condition attributes of the rule base in table14 is sorted in the order of priority as follows:
Priority(Fall)>Priority(Location)>Priority(Day)>Priority(Time)>Priority(Activity)>Priority (Incoming Call)>Priority(Temperature).

The priority of the attributes is user defined and is decided based on the importance for his day to day activities. (Life style pattern)

Fitness Degree: The fitness degree FD (R_j) for the Rule R_j is given by the equation,

$$\mathbf{FD(R_j)} = \frac{No\ of\ Matching\ Condition\ Attributes\ of\ Rule\ Base}{Total\ Number\ of\ Condition\ Attributes\ of\ Rule\ Base}$$

R_j will be recommended only if $FD(Rj) \geqq \tau$, where τ is threshold function and its value is user defined. For example, if the user wants at least 2 attributes like location and fall has to be matched for the rule base given in table14, then the threshold value can be adjusted to 2/7.
If suppose no full matching rule is found then the rule whose FD is maximum and greater than the threshold is selected. If no attributes gets matched then the new rule will be created and default value gets recommended.
Based on the above discussions the research work has proposed an algorithm illustrated in Fig9. The usage of the algorithm is discussed in the section case 6.3.1.4.

Input : 1) Current Context Attributes
2) Fuzzy_Rule Base (R,C,A)
3) The attributes are sorted in descending order of priority
Priority(C_1)> Priority(C_2)
Priority(C_2) > Priority (C_3)

Priority(C_{n-1}) > Priority(C_n)

Output : 1) Matched Rule with Condition attributes and Action Attributes.
2) Fitness degree of the Rule.

Algorithm :

for(Fuzzy_Rule#=1; Fuzzy_Rule#<=m; Fuzzy_Rule#++)
{If ($\exists$Fuzzy_Rule#|$\forall_{i,j=1}^{n}$ (Fuzzy_Rule#C_i==CC_j))
Then return
{ Fuzzy_Rule#; //Rule ID
$\forall_{i=1}^{n-1}$ Fuzzy_Rule#C_i; // Context Conditions Values
$\forall_{j=1}^{p}$ Fuzzy_Rule#A_j; // Action Values
FD(Fuzzy_Rule#); // Fitness Degree
}
Else If ($\exists$Fuzzy_Rule#|$\forall_{i,j=1}^{n-1}$ (Fuzzy_Rule#C_i==CC_j))
Then return
{ Fuzzy_Rule#;
$\forall_{i=1}^{n-1}$ Fuzzy_Rule#C_i;
$\forall_{j=1}^{p}$ Fuzzy_Rule#A_j;
FD(Fuzzy_Rule#);
}

Else If ($\exists$Fuzzy_Rule#|$\forall_{i,j=1}^{n-1}$ (Fuzzy_Rule#C_i==CC_j))
Then return
{ Fuzzy_Rule#;
$\forall_{i=1}^{n-1}$ Fuzzy_Rule#C_i;
$\forall_{j=1}^{p}$ Fuzzy_Rule#A_j;
FD(Fuzzy_Rule#);
}
}

Fig9: Fuzzy Rule based Algorithm (FRBA) to resolve conflict.

6.3.1.2. Bayesian Probability Based Algorithm (BPBA): The algorithm makes use of Bayesian theorem to recommend the appropriate service in a given context**.** The algorithm makes use of history database or log database for computing the Bayesian Probability of the service**.** Table15 illustrates one sample mobile phone call history database user (Teaching faculty)**.**

Table15 : Sample Call History Database of the Mobile Phone

Sl.No	Location	Day	Time	Activity	Incoming Call#	Action
1	Class Room	Mon	Class Hours	Taking Class	Unknown#	Rejected
2	Class Room	Mon	Class Hours	Taking Class	Known#X1	Rejected
3	Class Room	Mon	Class Hours	Taking Class	Known#X3	Rejected
4	Class Room	Mon	Class Hours	Taking Class	Known#X1	Accepted
5	Class Room	Mon	Class Hours	Taking Class	Known#X2	Accepted
6	Class Room	Mon	Class Hours	Taking Class	Known#X3	Rejected
7	Class Room	Mon	Class Hours	Taking Class	Known#X2	Accepted
8	Class Room	Mon	Class Hours	Taking Class	Known#X3	Rejected
9	Class Room	Mon	Class Hours	Taking Class	Known#X2	Accepted
10	Class Room	Mon	Class Hours	Taking Class	Known#X1	Rejected

According to the history database user rejects unknown number whenever the user is taking class. However with respect to the known numbers, for some known number the user adjusts the system to reject (or give auto answer) and for some number the user attends the call even if he is taking class.

The research work presented in this thesis makes use of Bayesian Probability based algorithm to estimate the action (service) to be recommended for a given context. The algorithm is as illustrated in the figure10.

Bayesian Probability based Algorithm(BPBA)

For given Context
For Service = 1 to Service = n

Compute: P(Service| Context) $= \frac{P(Context|Service)X\ P(Service)}{P(Context)}$

User Preferred Service = Service With Maximum P(Service|Context)

Fig10: Bayesian Probability based Algorithm

.

Where as

- **P(Service|Context)** is the posterior probability of hypothesis Service given the Context.
- **P(Service)** is the prior probability of Service.
- **P(Context)** is the prior probability of Context.
- **P(Context|Service)** is the conditional probability of observing Context in which Service holds good.

In the above example, the context is a set of values of attributes**;** {Location, Day, Time, Activity, Incoming call} and the action(service) is a set of attributes**;** { Rejected, Accepted}**.**The example includes four different contexts and two different actions as listed below**:**

C1: {ClassRoom, Mon, Class Hours, Taking Class, Unknown Number)

C2: {ClassRoom, Mon, Class Hours, Taking Class, Known Number X1)

C3: {ClassRoom, Mon, Class Hours, Taking Class, Known Number X2)

C4: {ClassRoom, Mon, Class Hours, Taking Class, Known Number X3)

A1: Rejected

A2: Accepted

The table16 illustrates the computed values of probabilities and Bayesian Probability of the respective context and actions**.**

Table16: Illustration of the usage of Bayesian Probability

Context	Actions	P(Actions)	P(Context/Actions)	P(Context)	P(Actions/Context)	Remarks
C1	**A1**	**6/10=0.6**	**1/6=0.16667**	**0.1**	**1.0000**	**100% Reject**
	A2	**4/10=0.4**	**0/4=0.0000**		**0.0000**	**0% Accept**
C2	**A1**	**6/10=0.6**	**2/6=0.3333**	**0.3**	**0.6666**	**66.66% Reject**
	A2	**4/10=0.4**	**1/4=0.2500**		**0.3333**	**33.33% Accept**
C3	**A1**	**6/10=0.6**	**0/6=0.0000**	**0.3**	**0.0000**	**0% Reject**
	A2	**4/10=0.4**	**3/4=0.7500**		**1.0000**	**100% Accept**
C4	**A1**	**6/10=0.6**	**3/6=0.5000**	**0.3**	**1.0000**	**100% Reject**
	A2	**4/10=0.4**	**0/4 = 0.0000**		**0.0000**	**0% Accept**

From the above illustration it is clear that the Bayesian probability of the acceptance for the known numberX2 is 100%**.** That is user always wishes to attend the call made by the number X2**,** whatever the situation may be**.**

The usage and illustration of the above algorithm is discussed in the section 6.3.1.4 to find the highest priority call in the context aware mobile phone.

6.3.1.3: Fuzzy Decision Table Based Algorithm (FDTBA)

The algorithm resolves the conflicts and recommends services making use of decision table. The decision table comprising the condition and action parts is the reduced form of huge rule base or history database. The decision table is obtained by removing the low profile attributes by applying the concepts of rough set theory. Since Z. Pawlak proposed the rough set theory in 1982**[113-115],** it has been successfully applied in many fields. Rough Set theory concepts discovers and reveals the inherent properties among data and thus extracts the high profile attributes which represents the entire rule base or which is capable to hold large amount of information.

In the presented research work the Rough set theory is used to derive the decision table from the large Rule base. The following are the basic concepts of the rough set theory that is used in this thesis:

1. Information System: A data set is represented as a table, where each row represents a context and services to be recommended. Every column represents an attribute (a variable, an observation, a property, etc.) that can be measured for each object; the attribute may be also supplied by a human expert or the user. Such table is called an information system. Formally, an information system is a pair IS = (U, A) in which ,

U is the universe (a finite set of objects, $U=\{x_1,x_2,\ldots..,x_m\}$

A is the set of attributes (features, variables) and

V_a is the set of values of attribute a, called the domain of attribute.

The table17 illustrates one example of information system.

Table17: Example Information System

S	Condition Attributes					Decision Attributes
	C1	C2	C3	C4	C5	D
S1	C1v1	C2v1	C3v1	C4v1	C5v1	D1
S2	C1v1	C2v1	C3v1	C4v1	C5v1	D1
S3	C1v1	C2v1	C3v1	C4v2	C5v2	D1
S4	C1v1	C2v1	C3v1	C4v1	C5v2	D1
S5	C1v1	C2v1	C3v1	C4v1	C5v2	D1
S6	C1v1	C2v2	C3v1	C4v3	C5v1	D2
S7	C1v1	C2v2	C3v1	C4v1	C5v3	D3
S8	C1v1	C2v2	C3v1	C4v1	C5v1	D3
S9	C1v1	C2v3	C3v1	C4v4	C5v1	D3
S10	C1v1	C2v3	C3v1	C4v5	C5v2	D3

Here U= S= {S_1, S2, S3, -------S_{10}}

A = {Condition Attributes, Decision Attributes}

V_{C1}= {C1v1}

V_{C2}= {C2v1, C2v2, C2v3}

V_D = {D1, D2, D3}

2. Indiscernibility Relations: Let I*S* = (S, A) be an information system consisting of set of situations/contexts S and set of actions A**.** For every set of attributes $B \subseteq A$ an indiscernibility relation IND (B) is defined in the following way**:**

IND_{IS} (B) = {(x,x$^{/}$**)** $\in S^2$ | $\forall$ a $\in$B a(x) = a(x$^{/}$**)}** is called the B-indiscernibility relation i.e the actions or attributes(a) corresponding to the situations x and x$^{/}$ will be identical i.e the objects x and x$^{/}$ are indiscernible (equivalent) from each other by attributes of the set B . The equivalence classes of B-indiscernibility relation are denoted as $[x]_B$**.** In the above example it is clear that S1and S2**,** S4 and S5 have the exactly the same values of attributes**.** The objects are (pair wise) indiscernible**.**

4. Dependency of Attributes: If D and C are the subsets of set A**.** The set D is said to be depends on C with degree *k* (0 ≤ *k* ≤1) if and only if

$$\mathbf{K = \gamma(C,D) =} \quad \frac{|POS_C(D)|}{|U|}$$

Where $POS_C(D)$ = $\cup_{x \in S/D} C(X)$ called a positive region of the partition U/D with respect to C**,** is the set of all elements of U that can be uniquely classified to blocks of the partition U/D**,** by means of *C***.** Dependency depends on the value of k as illustrated below **:**

- k=1 ⇒ D depends totally on C,
- k<1 ⇒ D depends partially (in a degree k) on C**.**

The coefficient k is known as degree of the dependency**.**

Example: Consider the information system given in the table17**.** For the information system different possible equivalent classes or indiscernibility relation are determined as follows

- The equivalent classes with respect to attribute C1 = { }
- The Equivalent Classes with respect to attribute C2= {{S1,S2,S2,S3,S4,S5},{S6,S7,S8},{S9,S10}}
- The Equivalent Classes with respect to attribute C3= { }
- The Equivalent Classes with respect to attribute C4= { {S1,S2,S4,S5,S7,S8}, {S9}, {S10}}
- The Equivalent Classes with respect to attribute C5 = { {S1,S2,S6,S8,S9}, {S3,S4,S5,S10}}
- The Equivalent Classes with respect to attribute D is , D= {{S1, S2, S3, S4, S5}, {S6}, {S7, S8, S9, S10}}

From the above equivalent classes the dependency degree of D with C1 is given by

K = γ(C1,D) = $\frac{|POS_{C1}(D)|}{|U|}$

= (Number of all the elements of C1 which can uniquely classify the equivalence classes of D) / |U|

= (Number of the elements of C1(Empty set containing 0 elements))/ |U|

= 0

Similarly

K = γ(C2,D) = $\frac{|POS_{C2}(D)|}{|U|}$

= (Number of all the elements of C2 which can uniquely classify the equivalence classes of D)/ |U|

= (Number of all the elements of C2 {{{S1,S2,S2,S3,S4,S5},{S6,S7,S8},{S9,S10}} which can uniquely classify the equivalence classes of D{{S1,S2,S3,S4,S5},{S6},{S7,S8,S9,S10}})/|U|

// Since the sets {S1,S2,S3,S4,S5} and { S9,S10} are present both in D as well as in C completely , those sets belongs to the positive region , whereas the sets {S6},{S7,S8,S9,S10} of D and {S6,S7,S8} are not present completely in both .Therefore the total number of elements present in both sets completely (belonging to positive region) is 7. Also the value |U|=10.

Therefore

K = 7/10 = 0.7 i.e The dependency of D on C_2 is 0.7

5. Reduct: A reduct is a set of attributes that preserves information of the information system. It means that a reduct is the minimal subset of attributes that represents the entire information system. In other words, attributes that do not belong to a reduct are superfluous with regard to classification of elements of the information system.

6. Core Attributes: If B and A are two sets such that B is a subset of A. Then the core of B is the set off all indispensable attributes of B. The relationship between core attributes and reducts is given by the equation:

Core (B) = $\cap \boldsymbol{Red}(\boldsymbol{B})$

Where *Red*(*B*) is the set of all reducts of *B*.

7. Decision Table*:* A decision table is a set of rows and columns. In which Rows represents the rules and columns represents the conditional attributes and decisions*. (Example Table3)*

Based on the above concepts of the rough set theory the research work has proposed an algorithm to determine the decision table for a given system as illustrated in Fig11. The usage of the algorithm is discussed in the section **6.3.1.5**.
To determine the decision table the algorithm makes use of the log file of the context aware system (mobile and TV).The log file which acts as a history database contains the service usage pattern from the starting date to ending date. The time period is user defined. In this research work three months duration is considered to build the history database for mobile and TV. The algorithm follows the divide and conquer strategy, and divides the history database into n number of small databases to simplify the task and improve the efficiency. In case of context aware TV system the algorithm splits the database into small database each representing the history TV viewing pattern for individual member of the family. If the family is made up of 4 members, then the algorithm splits the database into four small databases. Similarly in case of the context aware mobile system the algorithm splits the databases into n number of smaller databases, each representing the user mobile usage history database corresponding to unique location like college campus, outdoor, house,

public places, etc. For each small database the algorithm determines the reducts and hence constructs the decision table based on the minimal context attributes and actions.

Algorithm: (Construction of Decision Table)

Input: History database or Log database of respective context aware system
Output: Decision table with context (condition) attributes and actions

Step1: Split the History or Log Database into Different tables as per the requirement of the system.
The set of resultant databases = $\{d_1,d_2,d_3,\text{-------}d_n\}$

Step2*: for database =1 to database =n*
for i =1 to n
$IND(A\{a_1,a_2,a_3\text{---}a_i\}) = \{ (x,x') \in S^2 \mid \forall a \in A\ a(x) = a(x,x') \}$.
$Equivalent\_Classes(a_1,a_2,a_3,\text{-------}a_i)$, $[X]_A = IND(a_1,a_2,a_3\text{---}a_i)$;
end ***for***
end ***for***

Step3*: for each* $C_i = [X]_A$ *// Conditional attributes based equivalent classes*

$$\gamma_i(C_i,D) = \frac{|POS_C(D)|}{|U|}$$

Step4: Determine the Red(A) // Reducts are the classes with k= 1.

Step5: The Minimal reducts = CORED(A) = $\bigcap$ Red D(A)

Step6: The Decision Table is the table with Context Attributes and Actions,
Whereas Context _Attributes = The Minimal reducts = $\bigcap$ ***Red*** $_D$***(A)***

Fig11: Construction of Decision Table using Rough Set theory.

The recommendation system works in the similar way to that of rule based system. The difference is, in the place of rule base the system makes use of decision table.

6.3.1.4: Case Study1: Fuzzy Rule and Bayesian Probability Based Context Aware Mobile Phone

The usage of the proposed Fuzzy Rule Base Algorithm (FRBA) and Bayesian Probability base Algorithm (BPBA) is demonstrated by designing and developing context aware mobile phone. A number of sensors including accelerometers, temperature, time, location, etc., are embedded in the mobile phone to provide data about the user's context. For experiment purpose we used sensor board (embedded with sensors like accelerometer, temperature, humidity, Bluetooth transceiver) and mobile phone with Bluetooth enabled. We formulate the service adaptation process

by using artificial intelligence techniques like Bayesian Probability, fuzzy logic and rule based reasoning. Bayesian Probability to classify the incoming call (high priority call, low priority call and unknown calls), fuzzy linguistic variables and membership degrees to define the context situations and the rules for adopting the policies for implementing a service and service recommendation. The context aware mobile phone is tested for library and class room scenario to exemplify the proposed service recommendation engine and demonstrate its effectiveness.

The proposed recommendation engine for mobile utilizes the social locations like college campus, library and class room. The engine recommends the appropriate services like book search in library, appropriate notifications in class room and shopping application in outdoor to mention few. Table18 illustrates the list of different fuzzy set values, fuzzy linguistic terms and fuzzy membership function used in the case study for the respective context attributes along with their priority.

Table18: Fuzzy information of primitive context related to user.

Context Attributes	Priority	Fuzzy Set Values	Fuzzy Linguistic terms	Fuzzy Membership Function
Location	2	Home, College Campus, Library, Classrooms , Outdoors	low , fair , good, Excellent	Trapezoidal
Time	3	Sleepy Hours, Early Morning , Morning , Afternoon , Forenoon , Evening , Night , Late Night , Free Hours , Class Hours , Meeting Hours, BreakTime Library Hours , Sports Time	Yes ,No	Singleton Function
Weekday	4	Monday ,Tuesday, Wednesday ,Thursday , Friday, Saturday , Sunday , Holiday, Working Day	Yes ,No	Singleton Function
Physical	1	Fall , Normal	Yes, No	Singleton Function
Temperature	5	Current temperature in degree Celsius	Very Cold, Cold, Warm, Hot, Very Hot	Trapezoidal function

6.3.1.4.1 Recommendation Process: The procedure of service recommendation is as shown in the figure12. Accordingly the crisp input generated by different sensors will be translated into different fuzzy linguistic terms (as specified in table18). The recommendation engine accepts the context attributes in the fuzzy linguistic form and recommends the suitable actions by consulting rule base and situation history.

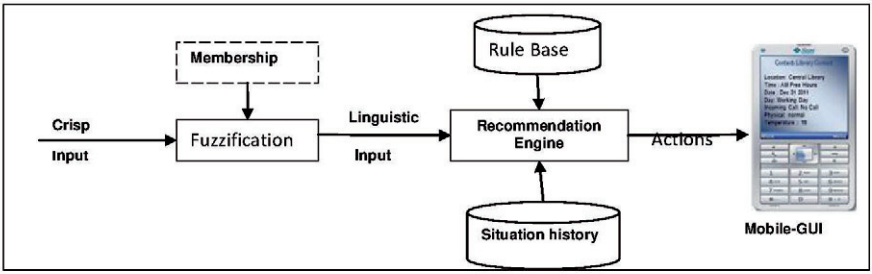


Fig12: Fuzzification process in Recommendation System.

6.3.1.4.2 System Data Modeling: In order to embed the user's context and social awareness in the mobile phone recommendation system, the system data was modeled into three domains of data: ***user's data, context data, and mobile content data.*** The research work proposed in thesis combines the three domains to provide personalize and socialize mobile phone applications making use of the proposed algorithm.

1. **Users domain** has information about user profiles, social roles and relationships between caller and call receiver.
2. **Context domain** represents the situations that link users with mobile phone and
3. **Mobile phone content domain** encapsulates mobile phone profiles, applications, menu items and settings metadata and their descriptors.

The three domains are conceptually orthogonal and as such act as independent sources of data for the mobile service recommendation problem. From these three data sources the mobile service recommender aims to predict purposeful service selections, given the past behavior of the member in different situations, based on the user and context features.

1. User Domain: The user is categorized into the Caller and Owner. Each user is represented as a vector of attributes like user type (Caller, Owner), mobile number, user role (Father, Mother, Friend, Boss, Colleague, Unknown, etc.,), and name. Whenever the user makes a call the call will be classified into High Priority Call, Medium Priority Call, Low Priority Call and Unknown call. Each user in his mobile phone will create separate clusters of contacts as High Priority, Normal Priority, Low

Priority and Unknown contacts. Table19 gives the details of service provide for each type of caller.

Table19: Accessibility Options for different Caller

Caller Priority	Services Provided
High	• All time – Accessible • Predefined Notification to owner
Medium	• Free Time – Accessible • SMS Notification to Owner • Free time slot announcement to caller • Diverting call to other number specified by the owner
Low	• Restricted Time– Accessible • SMS Notification to Owner • Restricted Time slot announcement to caller • Diverting call to other number specified by the owner
Unknown	• Restricted Time– Accessible • SMS Notification to Owner • Restricted Time slot announcement to caller

The priority can be assigned explicitly by the user. Implicitly the system can assign the priority of the user based on the social affinity between the caller and call receiver. The social affinity between two users depends on different factors as follows:

1. Call Acceptance
2. Call Rejection
3. Talk time between pairs of users.
4. Number of call between the users and hit ratio.

Algorithm: In order to resolve the conflict of the priority of incoming call priorities the system makes use of Bayesian Probability Algorithm discussed in the section 6.3.1.2. The system assigns the priority dynamically for all incoming calls based on the Bayesian probability of acceptance and rejection as illustrated in the fig13

If (user is unknown)
  Assign Priority as Undefined
else if (user is known)
{
S1 : **Compute** $P_{A=}$ **Probability(Acceptance/Context)**
S2 : **Compute Probability(Rejection/Context)**
S3: $\delta P = P_A - P_R$

$$\text{Priority} = \begin{cases} High & if\ \delta P > 0 \\ Medium & if\ \delta P == 0 \\ Low & if\ \delta P < 0 \end{cases}$$

}

Fig13: Assigning the priority to incoming call using Bayesian Probability.

2. Context domain: The system is designed to recommend the services based on the users context. User's context is derived based on the values of primitive contexts like location, time, weekday, temperature, incoming call and physical fall.

2.1: Location Context: In the proposed system, a set of Bluetooth access points was used for detecting location of user inside the college campus. Table20 illustrates the different access point mounted in the college campus for location detection. The location is determined using the Signal strength and MAC address of Bluetooth Access Point.

Table20: Bluetooth Access Points used for research

Sl.NO	Device	Mac Address	Location
1	BTAP1	00:0B:85:7356:8A	Outdoor
2	BTAP2	00:23:B4:A2:CO:A5	Admin
3	BTAP3	00:1B:24:2D:28:B8	CSE-Class Room
4	BTAP4	00:19:7E:5D:17:F5	Seminar Hall
5	BTAP5	00:4E:04:43:52:A2	CSE-Staff Room
7	BTAP7	54:9B:12:01:1E:D3	Library

The signal strength is expressed using fuzzy linguistic variable very low, low, good and excellent. For each linguistic variable the range of signal strength is fixed. For example the range of the low signal strength is fixed in between [0% to 30%].The low signal strength is spread across four points say a=0%,b=20%, c=25% and d= 30%.

Table21 : Lower and Upper Limit of Fuzzy Bluetooth Signal Strength

Linguistic Value	Range of Signal Strength			
	a	b	c	d
Low	0%	20%	30%	40%
Fair	30%	40%	50%	60%
Good	50%	60%	70%	80%
Excellent	70%	80%	100%	

The variations of the low signal strength of any given access point is a trapezoidal in nature as shown in the figure.

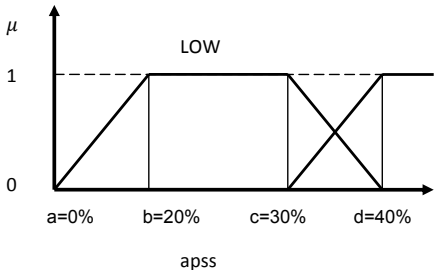


Fig14 : Trapezoidal Membership Function for low range signal

The variation of all types of signal strength (low/fair/good/excellent) is governed by the trapezoidal membership function (μ) given below:

$$\mu_{excellent}/\mu_{good}/\mu_{fair}/\ \mu_{low} = \begin{cases} 0 & if\ apss \le a \\ \frac{dx-a}{b-a} & if\ a \le apss \le b \\ 1 & if\ b \le apss \le c \\ \frac{d-dx}{d-c} & if\ c \le apss \le d \\ 0 & if\ apss \ge d \end{cases}$$

Whereas ***appss*** is the access point signal strength and dx is the difference between the two points.

Procedure followed in the research work to determine location of the user:

Consider the three locations in the vicinity of the campus say l_1, l_2 and l_3. The position of user will be associated with any one of these location based on the linguistic values for the membership functions $\mu_{excellent}$, μ_{good} , μ_{fair} and μ_{low}. The rule base considered in the system for identifying the location is as describe below:

If($\mu_{excellent}(l_1)>0.5 \ // \ \mu_{excellent}(l_2)>0.5 \ // \ \mu_{excellent}(l_3)>0.5$)

{ If ($\mu_{excellent}(l_1) > \mu_{excellent}(l_2)$ && $\mu_{excellent}(l_1) > \mu_{excellent}(l_3)$) then the location of the user is l_1

If ($\mu_{excellent}(l_2) > \mu_{excellent}(l_1)$ && $\mu_{excellent}(l_2) > \mu_{excellent}(l_3)$) then the location of the user is l_2

If ($\mu_{excellent}(l_3) > \mu_{excellent}(l_2)$ && $\mu_{excellent}(l_3) > \mu_{excellent}(l_2)$) then the location of the user is l_3

}

else If(For all locations $\mu_{excellent}$ *is* < 0.5*)*

If($\mu_{good}(l_1)>0.5 \ // \ \mu_{good}(l_2)>0.5 \ // \ \mu_{good}(l_3)>0.5$)

{ If ($\mu_{good}(l_1) > \mu_{good}(l_2)$ && $\mu_{good}(l_1) > \mu_{good}(l_3)$) then the location of the user is l_1

If ($\mu_{good}(l_2) > \mu_{good}(l_1)$ && $\mu_{good}(l_2) > \mu_{good}(l_3)$) then the location of the user is l_2

If ($\mu_{good}(l_3) > \mu_{good}(l_2)$ && $\mu_{good}(l_3) > \mu_{good}(l_2)$) then the location of the user is l_3

}

else If(For all locations $\mu_{excellent\ and}\ \mu_{good}$ *is <0.5)*

If($\mu_{fair}(l_1) > 0.5\ \ // \mu_{fair}(l_2) > 0.5\ \ // \mu_{fair}(l_3) > 0.5$)

{ If ($\mu_{fair}(l_1) > \mu_{fair}(l_2)$ && $\mu_{fair}(l_1) > \mu_{fair}(l_3)$) then the location of the user is l_1

If ($\mu_{fair}(l_2) > \mu_{fair}(l_1)$ && $\mu_{fair}(l_2) > \mu_{fair}(l_3)$) then the location of the user is l_2

If ($\mu_{fair}(l_3) > \mu_{fair}(l_2)$ && $\mu_{fair}(l_3) > \mu_{fair}(l_2)$) then the location of the user is l_3

}

else If(For all locations $\mu_{excellent\ and}\ \mu_{good\ and}\ \mu_{fair}$ *is <0.5)*

If($\mu_{low}(l_1) > 0.5\ // \mu_{low}(l_2) > 0.5\ // \mu_{low}(l_3) > 0.5$)

{ If ($\mu_{low}(l_1) > \mu_{low}(l_2)$ && $\mu_{low}(l_1) > \mu_{low}(l_3)$) then the location of the user is l_1

If ($\mu_{low\ r}(l_2) > \mu_{low\ r}(l_1)$ && $\mu_{low}(l_2) > \mu_{low}(l_3)$) then the location of the user is l_2

If ($\mu_{low}(l_3) > \mu_{low}(l_2)$ && $\mu_{low}(l_3) > \mu_{low}(l_2)$) then the location of the user is l_3

}

As an illustration consider a position of the user for which the membership functions say $\mu_{excellent}$, μ_{good} , μ_{fair} and μ_{low} for the locations like library, administrator office and College campus Outdoor will have the linguistic values as shown in the table22.

Table22: Example Fuzzy Membership values

Location	$\mu_{excellent}$	μ_{good}	μ_{fair}	μ_{low}
Library	1	0.0	0.0	0.0
Administrative Building	0.5	0.5	0.0	0.0
College Campus Outdoor	0.0	0.25	0.0	0.75

In such context, the system recognizes the position of user as library because $\mu_{excellent}$(Library) >0.5 >$\mu_{excellent}$(Admin) > $\mu_{excellent}$(Outdoor). The value 0.5 is considered because at this value, one membership value exceeds the other as it is obvious in the graph illustrated in fig14. This threshold value changes based on the upper and lower limit considered for different linguistic terms low, fair, good and excellent.

2.2: Time Context: The system reads a time from the system clock**.** Each fuzzy time is represented using a pair (L(t),TT)**.** Whereas L(t) is the symbolic notation for linguistic terms (ex: AM,PM,EG(Evening),NT(Night),MNT(MidNight),and EAM(Early Morning)) and TT is the Time Types (Free Hours , Working Hours , Break Time , Lunch Time ,Sleeping Hours)**.** The time will be mapped into its corresponding Linguistic terms using equation below**:**

$$L(t) = \begin{cases} AM & \text{if } t \in [6am \text{ to } 12pm] \\ PM & \text{if } t \in [12pm \text{ to } 5pm] \\ EG & \text{if } t \in [5pm \text{ to } 7pm] \\ NT & \text{if } t \in [7pm \text{ to } 12pm] \\ MNT & \text{if } t \in [12pm \text{ to } 3am] \\ EAM & \text{if } t \in [3am \text{ to } 5am] \end{cases}$$

2.3Temperature: The temperature was measured using the sensor embedded on the board. The temperature measured in degree celsius was mapped into fuzzy linguistic terms Very Cold, Cold, Warm, Hot and Very Hot using equation below **:**

$$L(Temp) = \begin{cases} \text{Very Cold} & \text{if temp} < 10 \\ \text{Cold} & \text{if temp} \in [10,20] \\ \text{Norm} & \text{if temp} \in [20,27] \\ \text{Warm} & \text{if temp} \in [27,32] \\ \text{Hot} & \text{if temp} \in [32,35] \\ \text{Very Hot} & \text{if temp} > 35 \end{cases}$$

2.4: Fall Detection: The fall of user is determined using the accelerometer readings of the mobile**.** The free fall period is very short and causes the amplitude of acceleration to drop below the threshold significantly**.** This sudden drop in amplitude generates a spike in the graph as illustrated in the Fig15**.** The flat line in the graph illustrates that the person is lying on the ground for a period of time after free fall**.**

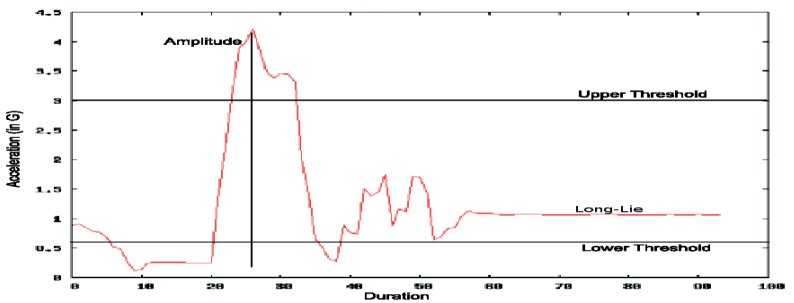


Fig15: Accelerometer reading when fall is detected (Source: Siewiorek et al.(2003))**[94]**

3. Mobile phone content domain: Mobile phone is modeled in terms of its services and settings. The contents of mobile phone service and settings can be classified into incoming call, call settings, volume settings, profile, desktop applications and hidden applications. User usually prefers services and settings based on her context. For experiment purpose we have considered services and settings related to the user's situation in college campus.Table23 illustrates the services and settings provided based on the context of user. Table24 lists some of the allowable choice for some of the services and Settings.

Table23: Context based Mobile services and Settings

Context	Services and Settings Provided
Location	• Location (Class room , Library ,Outdoor , etc) discovery • Location specific settings and service as predefined by owner • For example when owner visits library mobile goes to silent mode and provides a library related services like books (journal/ newspaper /digital library) search , friends search ,internet link ,notifications and accessibility to high priority call in silent mode to mention few.
Time	• Identifying time as working hours ,free hours ,class hours ,break hours ,lunch hours ,etc • Time Specific settings and service. • For example when owner is in classroom the services and settings changes when time changes from class hours to free hours
Weekday	• Classifies the day as working day or holiday
Physical	• Determines whether the user is in normal or fall condition • If he/mobile is in fall condition it provides the necessary notification as predefined by the owner.
Temperature	• Identifying the temperature as cold, very cold ,hot and very hot • Temperature specific settings and service as predefined by owner • For example if the temperature is very cold the mobile invokes the application providing the details of coffee/ hot snacks availability in the college campus.

Table24: Mobile Services and Settings with allowable choices

Services/Settings	Allowable Choices/types
Incoming Call	High Priority Call , Low Priority Call, Unknown Call ,No Calls
Call Settings	Call Ringing , Call Vibrating , Answer the call , Reject the call , Call Divert
Volume Settings	High, Medium , Low , Silent
Profile	General , Silent
Desktop Applications	Messaging, My_Shopping , My_Social_Site , My_Library, My_Groups, My_College, Radio, TV, Camera, Video , My_Music, Games, Voice_Recorder, My_Entertainment, Organizer, Alarm, Calendar, Internet, Hidden_Applications, Notifications
Hidden Applications	Context info, Settings, Notifications, All applications which are not on the desktop.

6.3.1.4.3 Architecture of Recommendation Engine: The layered architecture (discussed in the chapter 5) was used for implementing context aware mobile as illustrated in the figure16. The input provided by different embedded physical and logical sensor like system clock, temperature sensor, accelerometer, calendar and user profile is fuzzified into respective linguistic terms in the fuzzification layer. In the context layer the user context is generated using the fuzzified sensor values. The resultant context will be stored in the form of vector containing the value for the elements day, time, location, temperature and fall. In the recommendation layer suitable actions gets recommended for newly generated user context.

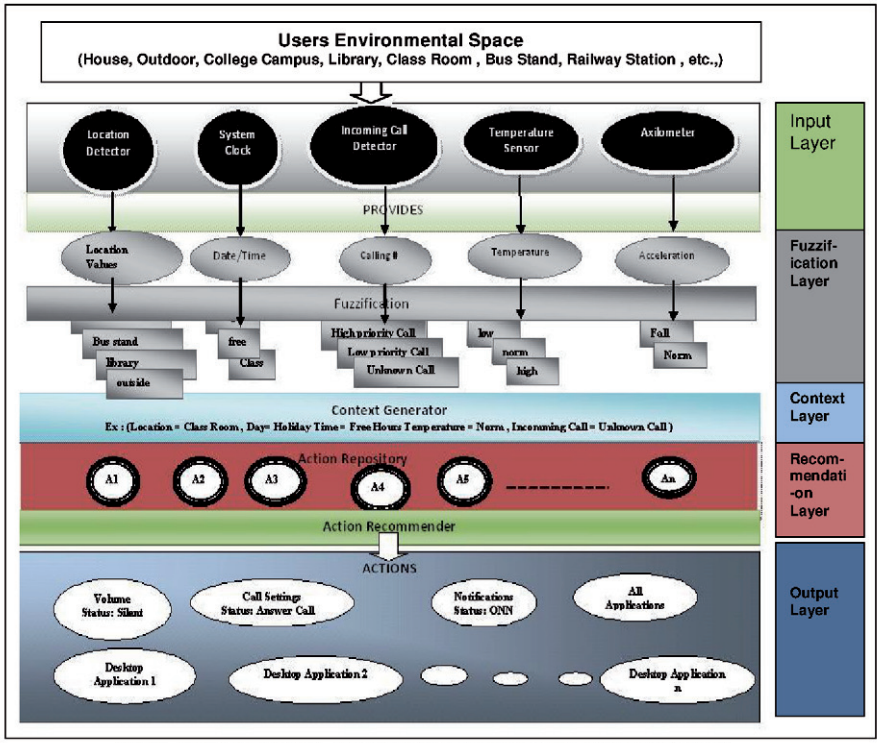
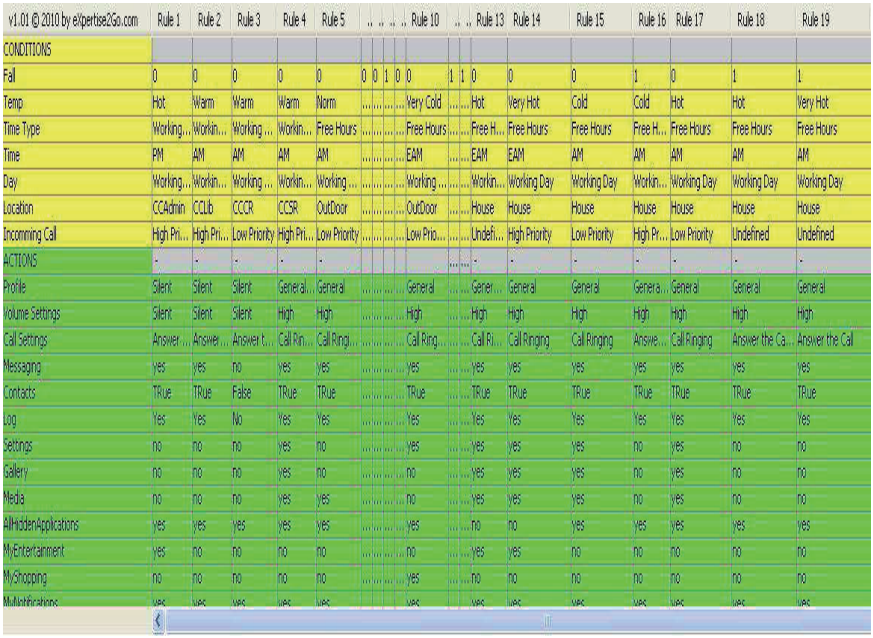


Fig16: Architecture of the proposed recommendation Engine for cell phone

6.3.1.4.4 Rule Base: The rule base is build making use of the log file of one month usage history of mobile. The rule base presented in this thesis is designed making

use of the tool **e2grulewriter, v1.01, 2010 by expertise2Go.com**. The snapshot of few rules with condition and actions is as illustrated in the figure17 below**.**



v1.01 © 2010 by eXpertise2Go.com	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	.. ..	Rule 10	.. ..	Rule 13	Rule 14	Rule 15	Rule 16	Rule 17	Rule 18	Rule 19
CONDITIONS															
Fail	0	0	0	0	0	0 0 1 0	0	1 1	0	0	0	1	0	1	1
Temp	Hot	Warm	Warm	Warm	Norm	.....	Very Cold	.....	Hot	Very Hot	Cold	Cold	Hot	Hot	Very Hot
Time Type	Working...	Workin...	Working ...	Workin...	Free Hours	.....	Free Hours	.....	Free H...	Free Hours	Free Hours	Free H...	Free Hours	Free Hours	Free Hours
Time	PM	AM	AM	AM	AM	.....	EAM	.....	EAM	EAM	AM	AM	AM	AM	AM
Day	Working...	Workin...	Working ...	Workin...	Working ...	.....	Working ...	.....	Workin...	Working Day	Working Day	Workin...	Working Day	Working Day	Working Day
Location	CCAdmin	CCLib	CCCR	CCSR	OutDoor	.....	OutDoor	.....	House	House	House	House	House	House	House
Incomming Call	High Pri...	High Pri...	Low Priority	High Pri...	Low Priority	.....	Low Prio...	.....	Undefi...	High Priority	Low Priority	High Pr...	Low Priority	Undefined	Undefined
ACTIONS	-	-	-	-	-	.....		.....	-	-	-	-	-	-	-
Profile	Silent	Silent	Silent	General...	General	.....	General	.....	Gener...	General	General	Genera...	General	General	General
Volume Settings	Silent	Silent	Silent	High	High	.....	High	.....	High	High	High	High	High	High	High
Call Settings	Answer ...	Answer...	Answer t...	Call Rin...	Call Ringi...	.....	Call Ring...	.....	Call Ri...	Call Ringing	Call Ringing	Answe...	Call Ringing	Answer the Ca...	Answer the Call
Messaging	yes	yes	no	yes	yes	.....	yes	.....	yes	yes	yes	yes	yes	yes	yes
Contacts	TRue	TRue	False	TRue	TRue	.....	TRue	.....	TRue	TRue	TRue	TRue	TRue	TRue	TRue
Log	Yes	Yes	No	Yes	Yes	.....	Yes	.....	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Settings	no	no	no	yes	no	.....	yes	.....	yes	yes	yes	no	yes	no	no
Gallery	no	no	no	yes	no	.....	no	.....	yes	yes	yes	no	yes	no	no
Media	no	no	no	yes	yes	.....	no	.....	yes	yes	yes	no	yes	no	no
AllHiddenApplications	yes	yes	yes	yes	yes	.....	yes	.....	no	no	yes	yes	yes	yes	yes
MyEntertainment	yes	no	no	no	no	.....	no	.....	yes	yes	no	no	no	no	no
MyShopping	no	no	no	no	no	.....	yes	.....	no	no	no	no	no	no	no
MyNotifications	yes	yes	yes	yes	yes	.....	yes	.....	yes	yes	yes	yes	yes	yes	yes

Fig17 : Rule Base for context aware mobile

For selecting the appropriate rule the Fuzzy Rule based algorithm described in the section 6.3.1.1(Fig9) is utilized**.** The algorithm initially searches for rule where all the condition attributes and context attributes will be same**.** If not found the algorithm searches the rule wherein the n-1 attributes(deleting the least priority attribute)**.**At each time the algorithm searches for best rule by deleting the least priority attribute and thus maintaining the best fitness degree (>=τ)**.**

6.3.1.4.5 Experimental Observations and Result Analysis: The Experiment was conducted under two phases**: Phase1**: Using Simulator **Phase2:** Using Experimental Set with devices and sensors**.**

Phase 1: In this phase the proposed system was tested using simulator developed inJ2ME. Following is one of the several scenarios tested using simulator.

***Scenario (User is in Central Library)*:** In this scenario the user was allowed to carry the mobile phone to Library Hall. A soon as the user enters into the library hall Mobile phone switches into the Library Context from the previous context (Fig18.1 and Fig18.2). The Mobile phone adapts the settings and services as per the requirement of the situation (Fig18.3). The user was allowed to use the library service (say book search) which is illustrated in the figures (Fig18.4 to Fig18.9).

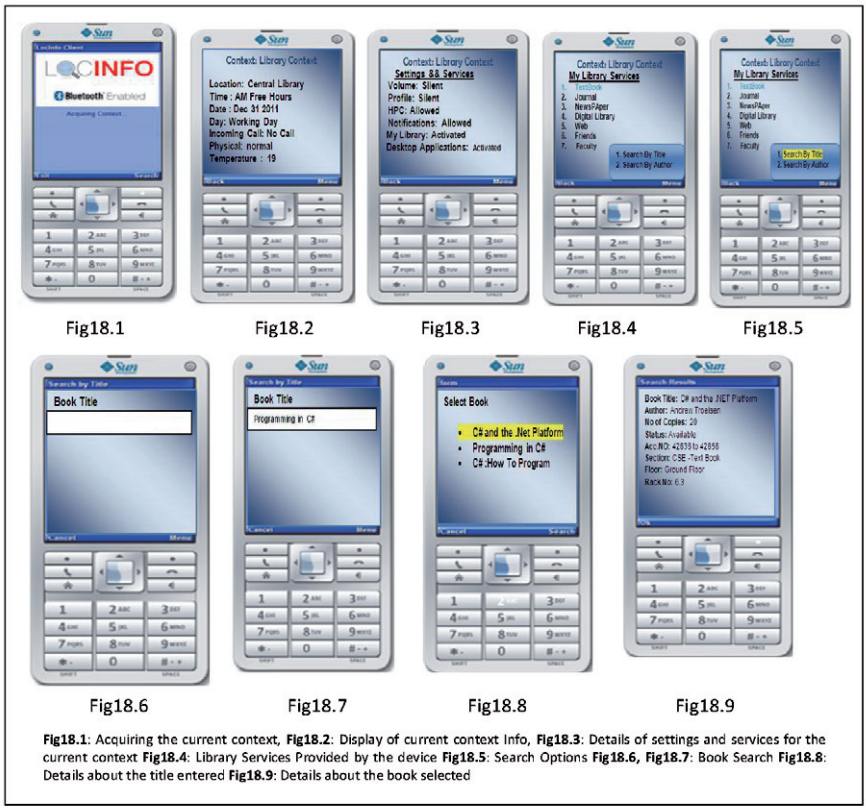


Fig18.1 Fig18.2 Fig18.3 Fig18.4 Fig18.5

Fig18.6 Fig18.7 Fig18.8 Fig18.9

Fig18.1: Acquiring the current context, **Fig18.2**: Display of current context Info, **Fig18.3**: Details of settings and services for the current context **Fig18.4**: Library Services Provided by the device **Fig18.5**: Search Options **Fig18.6, Fig18.7**: Book Search **Fig18.8**: Details about the title entered **Fig18.9**: Details about the book selected

Fig 18: Different states of Context aware Mobile in Library.

Phase 2: The experimental set up for the realization of the concept is as shown in the figure19. The system consists of 5 major components which are described in the following sections.

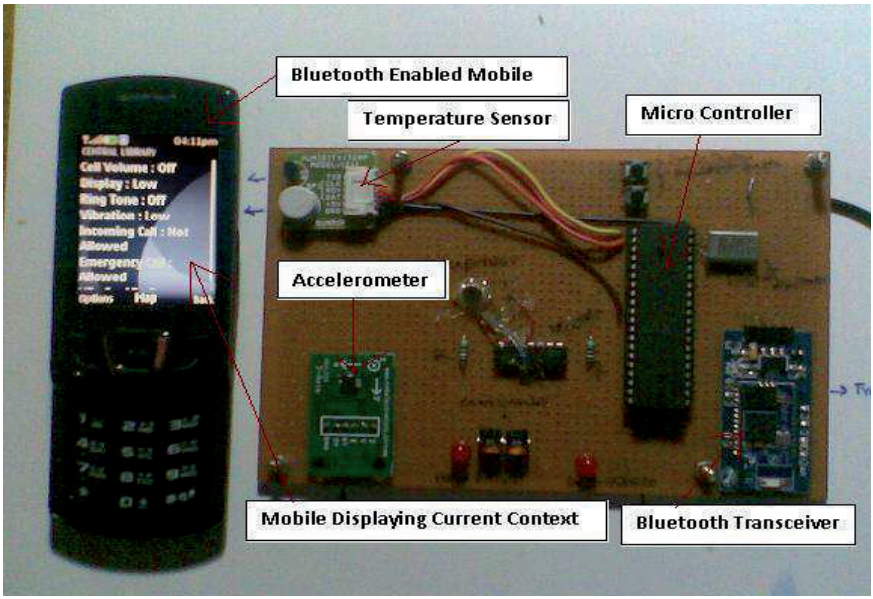


Fig19 : Experimental set up of context aware mobile

1. Context aware Mobile Phone (CAMP): is enabled with Bluetooth, GPRS and supporting Symbian Operating System, which supports J2ME. On the mobile side, the application was developed and implemented using Java 2 micro edition (J2ME). The J2ME application runs on any Symbian OS based phone.

2. Sensor Board: The sensor board was designed specifically for the concept demonstration. Sensors like temperature sensor and accelerometer was embedded in the sensor (however the latest mobile will have inbuilt temperature and accelerometer). Bluetooth transceiver was used to establish the communication between sensor board and Mobile.

3 Database: The server used a MySQL database. MySQL is an open source relational database management system which uses Structured Query Language (SQL). MySQL was chosen because of its reliability, speed and flexibility. The server receives requests from the application program. The request can be either to

register a new user, update user information, or locate an existing user. The server tokenizes the user requests, and issues the appropriate SQLstatement to perform the required action.

4. **Server:** The Netbeans IDE6.9.1 was used to develop server. In addition Wamp server was installed in a system so that database can be accessible for the Server.

5. **Client: The** client application was developed in J2ME and installed in Bluetooth Enabled Cell.

Experiment 1: This experiment was conducted to determine the Bayesian Priority assignment accuracy (BPAA) of proposed algorithm in classifying the Incoming call as High priority call, Low Priority Call and Unknown Call. Three different user's one month mobile usage history database with sample size of 1000, 500 and 100 per month respectively was used as a training database for the algorithm. As illustrated in the figure20 the performance was better for database with more number of samples per month.

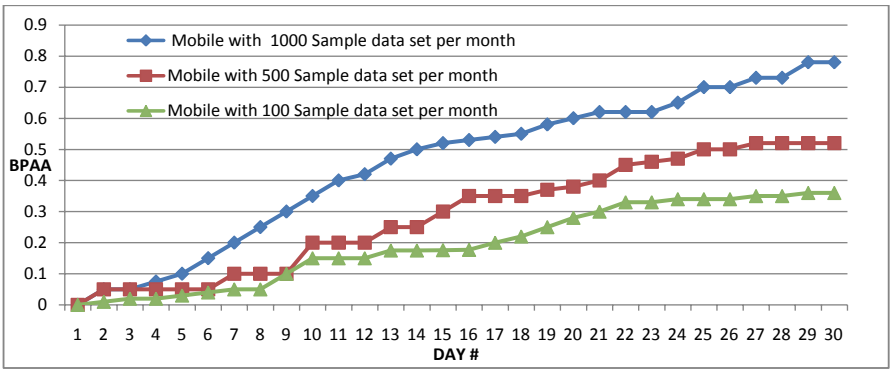


Fig20 : Priority Assignment Accuracy of Bayesian Network in CAMP

Experiment 2: This experiment was conducted to determine the amount of time required to recognize the different location with respect to Bluetooth access point signal strength. For each location three different trials were made with different signal strength. As it is illustrated in the Fig21 the response time was less (50-100

milli seconds) for excellent signal strength as compared to low signal strength (1000 -1500 milli seconds).

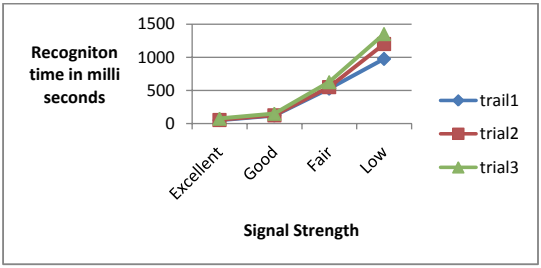


Fig21: Time to recognize the different location based Bluetooth Signal strength in CAMP

Experiment 3: This experiment was conducted to determine the average service popup time with respect to different location. The system took more time when user moved to outdoor as compared to that when the user is in class room. This is due to the fact that the number of services to be invoked in outdoor situation is more as compared with the class room situation.

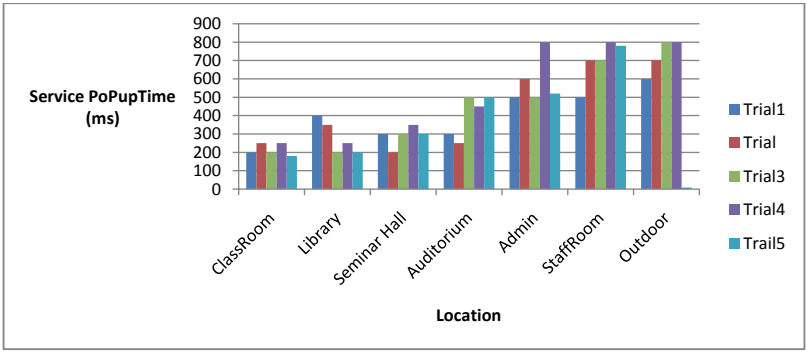


Fig22: Average Service popup time of Mobile Applications in CAMP

Experiment 4: This experiment was aimed to evaluate the precision of recommending the appropriate services and settings based on the current context of the user. About 20 users (students and faculty) were allowed to use the mobile in college campus in different locations. The result is highly subjective. Most users agree that the precession rate of 76-82 percent is useful.

$$\text{Precision} = \frac{Nuseful}{Ntotal}$$

Where N_{useful} = No of services (Expected by the user ∩ Recommended by the system)

N_{total} = No of Services (Recommended by the system ∪ Expected by the user)

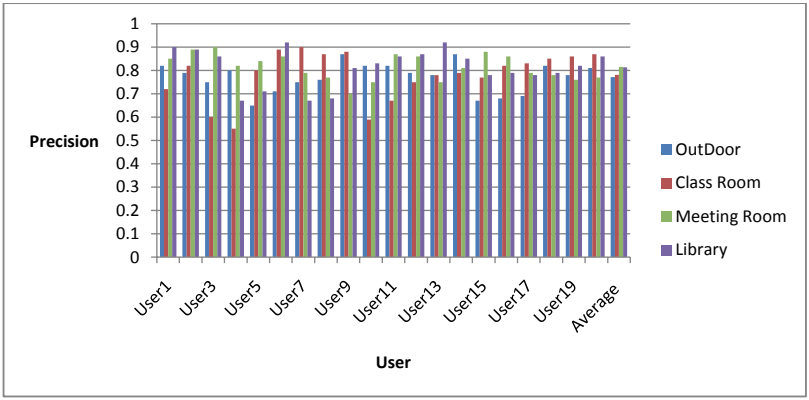


Fig23 : Precision of service recommendation in different context in CAMP

Experiment 5: This experiment was aimed to evaluate the overall performance of the recommendation system in terms of time.

Table25: Overall Performance of CAMP Recommendation System

Tasks	Time
Context Discovery	1s – 3s
Rule Matching	10 ms - 1s
Settings adjustment	1s – 2s
Services invoking	100ms -1s
Total	2.11s to 7s

Experiment 6: To get the proper assessment of the application a survey on a group of 20 people on the usability and usefulness of the application was made in the college campus. First the demonstration of prototype application was organized. The distribution of the participants was as follows: 8 undergraduate students, 8 post graduate students and 4 faculty members. A set of questions about the application was handed over to each participant and were requested to answer them on a scale of 1 to 5 of satisfaction level. The questionnaire used for the survey is given below:

Overall, how would you rate the following services provided by the context aware mobile in terms of satisfaction level? (1 = Below Average, 2= Average 3= Good 4 = Very Good 5 = Excellent)

1. Location based Services
2. Time based services
3. Incoming Call based Services
4. Fall based services
5. Temperature based services
6. System Performance

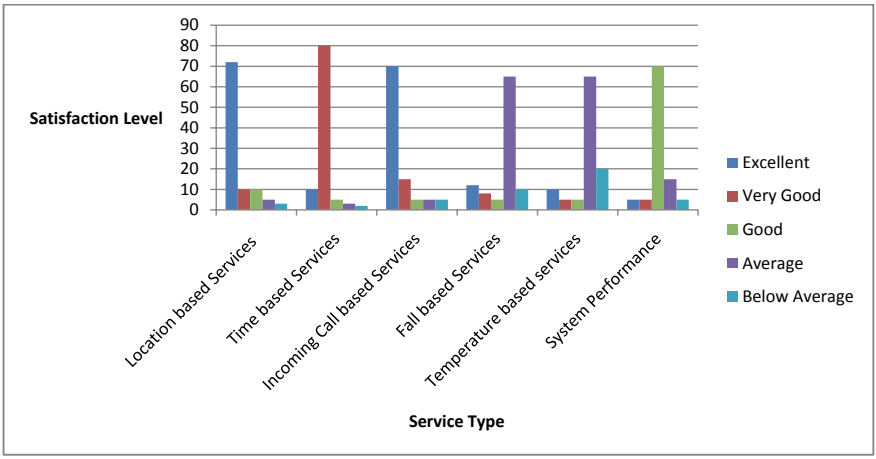


Fig24 : Average user satisfaction level of different users for different services provided by the CAMP system.

From the graph, it is evident that participants were enthusiastic about the application and its usability.

6.3.1.5 CaseStudy2: Fuzzy Rule, Bayesian Probability and Decision Table Based Context aware Mobile Phone.

In this case study the recommendation engine of cell phone is designed using decision table in the place of rule base as discussed in the previous case. The decision table is derived by applying the concepts of rough set theory. The algorithm and the basic concepts of rough set theory used to derive the decision table is presented in the section 6.3.1.3.

The architectural diagram for the proposed system is illustrated in the figure25 .

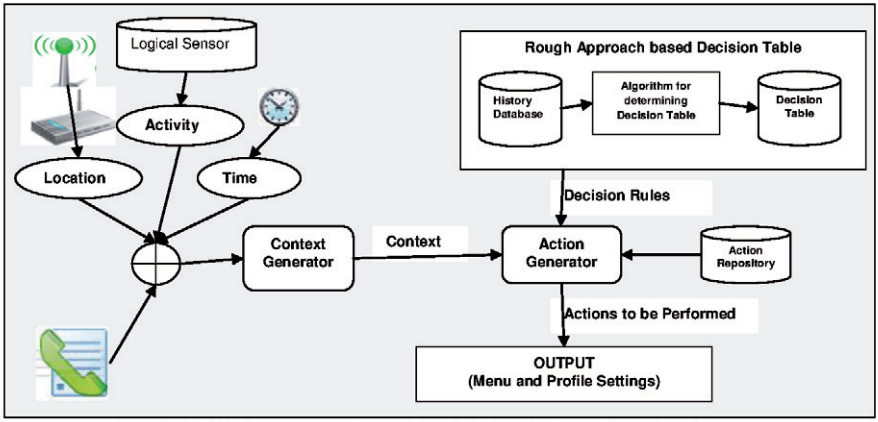


Fig25 : Architecture of the Proposed Decision Table based CAMP system.

Initially the system generates the context by determining the location (using wifi access points), time-date (using system clock), activity (using logical sensors i.e. user stored profiles) and status of incoming call. The actions are recommended making use of fuzzy rough set based decision table. The decision table is created making use of history database. History database is created by making use of users mobile usage log files for fixed period of time. The action recommender recommends the appropriate service based on the decision table.

6.3.1.5.1 Construction of Decision Table: To begin with, in order to generate a history database of one month all required set of condition attributes and decision attributes were identified and listed as illustrated in table26. A snapshot of the history database created for the experiment purpose is given in Fig26.

Table26: Information of Context Attributes and Decision attributes

Attribute	Description with Symbolic notations	Examples
Date	Day-Month-Year	12-2-2011
Day	**C1**: Sunday(1), Monday(2) , Tuesday(3), Wednesday(4),Thursday(5), Friday(6),Saturday(7),. **C2**: Working Day(1) ,Holiday(0)	**11**-Sunday ,Working Day **21**-Monday,Working Day **20**- Monday , Holiday
Time	**C1**:Morning(AM) ,Afternoon(PM), Evening(EG) ,Night(NT) **C2**: Free Hours(FH), Class Hours(CH) , Break Time(BT) , Lunch Time(LT), Sleeping Hours(SH).Working Hours(WH)	**AMFH**- Morning Free Hours **PMCH-** Afternoon Class Hours **EGFH**- Evening Free hours
Location	1.House (H) , College Campus(CCO) ,Library (LH),Class Room(CR) , Staff Room (SR) .Auditorium (AD) , Pubic Places(PP) ,Hostel(HL),Canteen(Cn), MESS(MS),	**H**- House **HL** – Hostel **CCO**- College Campus Outdoor
Activity	Meeting (Mt),Dinner (Dr),Lunch (L),Working(Wg),Playing (Pg) ,Studying(St), Watching TV (WTV),Getting Ready (GR),Sleeping (Sg),Driving (DG),Hostel(HL),Lecture(LC)	**Mt**- Meeting **Dr**- Dinner **Lc**- Lunch **Wg**-Working **Pg**- Playing **St**- Studying
Incoming Call	**1**. High Priority Call(HPC) **2**. Low Priority Call(LPC) **3**. Unknown Calls(UC) 4.No Calls	**HPC**- High Priority Call
Call Settings	1. Call Ringing 2.Call Vibrating 3. Answer the Call 4. Reject the call 5.Call Divert	CS1 - Call Settings Call Ringing CS2 - Call Settings Call Vibrating CS3 - Call Settings Answer the Call CS4 - Call Settings Reject the Call CS5 – Call Settings Call Divert
Volume Settings	1.High 2.Medium 3.Low 4.Silent	VS1- Volume Settings High VS1- Volume Settings Medium VS1- Volume Settings Low VS1- Volume Settings Silent
Profile	1.General 2.Silent	P1 – Profile General P2- Profile Silent
Desktop Applications	1.Messaging 2.MyShoping 3.My Social Site 4.MyLibrary 5.MyGroups(Friends,Teachers,Parents,etc) 6.MyCollege 7.Radio 8.TV 9.Camera 10.Video 11.MyMusic 12.Games 13.VoiceRecorder 14.MyEntertainment 15.Organizer 16.Alarm 17.Calendar 18.Calculator 19.Internet 20.Hidden Applications	DA1- Desktop Applications Messaging DA2- Desktop Applications My Shopping DA3- Desktop Applications Social Site DA4 - Desktop Applications MyGroups DA5- Desktop Applications My Library DA6- Desktop Applications My College DA7- Desktop Applications Radio DA8- Desktop Applications TV DA9- Desktop Applications Camera DA10- Desktop Applications Video DA11- Desktop Applications My Music DA12- Desktop Applications Games DA13- Desktop Applications Voice Recorder DA14- Desktop Applications MyEntert. DA15- Desktop Applications Organize DA16- Desktop Applications Alarm DA17- Desktop Applications Calendar DA18- Desktop Applications Calculator DA19- Desktop Applications Internet DA20- Hidden Applications
Hidden Applications	1.Context info 2.Settings 3.Notifications 4. All applications which are not on the desktop	DA20

Making use of history database a set of information database systems was designed for each location like Classroom, Hostel, Canteen, Admin, Library and College Campus outdoor. Each location based information system was allowed to undergo rough set analysis (as discussed in the section 6.3.1.3) to identify the core attributes to design the location based decision table.

	ROLE:STUDENT		MOBILE:+918147008218						
Date	Day Context	Time Context	Location	Activity	Incoming Call	Call Settings	Volume Settings	Profile	Desktop Applications
1/11/2011	31	AMSH	HL	Sg	HPC	CS1	VS1	P1	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,
1/11/2011	31	AMBFT	MS	Bf	HPC	CS2	VS1	P2	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,
1/11/2011	31	AMFH	HL	GR	HPC	CS1	VS1	P1	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,
1/11/2011	31	AMCH	CR	LC	HPC	CS2	VS4	P2	DA14,DA15,DA17,DA18,DA25,DA26
1/11/2011	31	AMCH	CR	LC	UC	CS2	VS4	P2	DA14,DA15,DA17,DA18,DA25,DA26
1/11/2011	31	AMCH	CR	LC	LPC	CS2	VS4	P2	DA14,DA15,DA17,DA18,DA25,DA26
1/11/2011	31	AMBT	CR	Hf	HPC	CS2	VS4	P2	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,
1/11/2011	31	AMBT	CCO	T	HPC	CS1	VS1	P1	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,
1/11/2011	31	AMBT	CCO	T	LPC	CS1	VS1	P1	DA1,DA2,DA3,DA4,DA5,DA6,DA7,DA8,D DA11,DA12,DA13,DA14,DA15,DA16,DA1 A19,DA20,DA21,DA22,DA23,DA24,DA25,

Fig26 : A snapshot of the history database used in decision table based CAMP.

In the following section the construction of the decision table for context aware mobile system is explained by considering the small segment (a set of 20 tuples) of large information (a set of 1200 tuples) .

Consider a sample information system of context aware mobile as shown in Table 26. The information system consists of a set of 20 tuples (Situation objects s1,s2,s3---s20) each consisting two attributes sets **:**

1. Condition attributes, **C** = {Day, Time, Location, Activity, Incoming Call} and

2. Decision Attributes **D** = {Call settings, Volume Settings, Profile Setings,Desktop Applications} .

Based on the frequency of usage of the services by the mobile user the following three decision vectors were considered.

Dv_1 = {DA_1, DA_2, DA_4, DA_6, DA_{17}, DA_{18}, DA_{20}, DA_{21}}

Dv2={ DA_1 , DA_2 , DA_3 , DA_4 ,DA_6 , DA_7 ,DA_8 ,DA_9 ,DA_{10} ,DA_{11} ,DA_{12} ,DA_{13} ,DA_{14} ,DA_{15} ,DA_{16} , DA_{17}, DA_{18}, DA_{19}, DA_{20}, DA_{21}}

Dv3= { DA_{16} ,DA_{20} ,DA_{21}}

i.e

D = {Dv_1,Dv_2,Dv_3}

Table27:Information System of Context aware Mobile Phone

S	Condition Attributes					Decision Attributes
	Day	Time	Location	Activity	Incoming Call	
S1	Day_{v1}	T_{v1}	L_{v1}	A_{v1}	IC_{v1}	Dv1
S2	Day_{v1}	T_{v1}	L_{v1}	A_{v1}	IC_{v1}	Dv1
S3	Day_{v1}	T_{v1}	L_{v1}	A_{v2}	IC_{v2}	Dv1
S4	Day_{v1}	T_{v1}	L_{v1}	A_{v1}	IC_{v2}	Dv1
S5	Day_{v1}	T_{v1}	L_{v1}	A_{v1}	IC_{v2}	Dv1
S6	Day_{v1}	T_{v2}	L_{v1}	A_{v3}	IC_{v1}	Dv2
S7	Day_{v1}	T_{v2}	L_{v1}	A_{v1}	IC_{v3}	Dv3
S8	Day_{v1}	T_{v2}	L_{v1}	A_{v1}	IC_{v1}	Dv3
S9	Day_{v1}	T_{v3}	L_{v1}	A_{v4}	IC_{v1}	Dv3
S10	Day_{v1}	T_{v3}	L_{v1}	A_{v5}	IC_{v2}	Dv3
S11	Day_{v1}	T_{v3}	L_{v1}	A_{v5}	IC_{v1}	Dv3
S12	Day_{v1}	T_{v4}	L_{v1}	A_{v6}	IC_{v1}	Dv3
S13	Day_{v1}	T_{v4}	L_{v1}	A_{v6}	IC_{v2}	Dv3
S14	Day_{v1}	T_{v4}	L_{v1}	A_{v6}	IC_{v3}	Dv3
S15	Day_{v1}	T_{v4}	L_{v1}	A_{v7}	IC_{v1}	Dv3
S16	Day_{v1}	T_{v4}	L_{v1}	A_{v7}	IC_{v2}	Dv3
S17	Day_{v1}	T_{v4}	L_{v1}	A_{v6}	IC_{v1}	Dv3
S18	Day_{v1}	T_{v5}	L_{v1}	A_{v8}	IC_{v1}	Dv4
S19	Day_{v1}	T_{v5}	L_{v1}	A_{v8}	IC_{v1}	Dv4
S20	Day_{v1}	T_{v5}	L_{v1}	A_{v8}	IC_{v1}	Dv4

It is clear from the information system that the objects S1 and S2, S4 and S5 *as* well as S5, S18, S19, and S20 have exactly the same values of attributes. The objects are (pair wise) indiscernible. In order to illustrate how a decision system from table 27 defines indiscernibility relation, the following non-empty subsets of the conditional attributes: **{Day, Time, Location, Activity and Incoming Call}** was considered for generating a decision table. The power set generated for the conditional attributes are**:**

{{Day}, {Time}, {Location}, {Activity}, {Incoming Call},{Day, Time }, {Day, Location} ,{Day, Activity}, {Day, Incoming Call}, {Time, Location}, {Time, Activity}, {Time, Incoming-Call}, {Location, Activity}, {Location, Incoming Call}, {Activity, Incoming Call}, {Day, Time, Location}, {Day, Time, Incoming Call}, { Day ,Time ,Activity}, {Day, Location, Activity}, {Day, Location ,Incoming Call}, {Day, Activity, Incoming Call}, {Time, Location, Activity}, {Time, Location , Incoming Call}, {Time, Activity, Incoming Call}, {Location, Activity, Incoming Call}, {Day, Time, Location, Activity}, {Day, Time, Location, Incoming Call}, {Day, Time, Activity, Incoming call}, {Day, Location, Activity, Incoming Call} ,{Time, Location, Activity, Incoming Call }, {Day, Time , Location, Activity and Incoming Call}.

By applying the theory of rough sets (as discussed in the section 6.3.1.3), the equivalence classes generated between every element of power set and the

decision attributes, the computed dependency degree of attributes are listed in the table28 below:

Table 28: Dependency Degree of Conditional Attributes with respect to decision attributes

C	$\Upsilon(C,D) = \frac{\lvert POS_C(D)\rvert}{\lvert U\rvert}$	C	$\Upsilon(C,D) = \frac{\lvert POS_C(D)\rvert}{\lvert U\rvert}$
{ Day }	0	{Day,Time,Incoming Call}	0.65
{ Time }	0.85	.{ Day ,Time ,Activity}	1
{ Location }	0	.{Day,Location,Activity}	0.7
{ Activity }	0.7	{Day, Location ,Incoming Call}	0.1
{ IncomingCall}	0.1	{Day, Activity, Incoming Call}	0.85
{ Day, Time }	0.85	{Time , Location, Activity}	1
{Day, Location}	0	{Time ,Location ,Incoming Call}	0.9
{Day, Activity}	0.7	{Time ,Activity ,Incoming Call}	1
{Day, Incoming Call}	0.1	{Location,Activity ,Incoming Call}	0.85
{Time, Location}	0.85	{Day,Time,Location,Activity}	1
{Time, Activity,}	0.8	{Day,Time,Location,Incoming Call}	0.9
{Time, Incoming Call}	0.9	{Day,Time,Activity,Incomming call}	1
{Location, Activity}	0.75	{Day,Location,Activiy,Incomming Call}	0.85
{Location , Incoming Call}	0.1	{Time,Location,Activity,Incoming Call}	1
{ Activity , Incoming Call}	0.85	{ Day, Time ,Location, Activity and Incoming Call}	1
{Day,Time,Location}	0.9		

The set of attributes with k=1 are called reducts or total dependency attributes. Therefore the total dependency attributes i.e. a set of reducts

= {{Day, Time, Activity}, {Time, Location, Activity}, {Time, Activity, Incoming Call}, {Day, Time, Location, Activity}, {Day, Time, Activity, Incoming call}, {Time, Location, Activity, Incoming Call} and {Day, Time, Location, Activity and Incoming Call}}

In the above set of reducts two categories of subsets of C was discovered one with the cardinality four and the other with the cardinality 3.

Set of Reducts with cardinality four = { $\mathbf{R_{41}}$ = {Day, Time, Location, Activity} , $\mathbf{R_{42}}$ = {Day, Time, Activity, Incoming call} , $\mathbf{R_{43}}$ = {Time, Location, Activity, Incoming Call} and $\mathbf{R_{44}}$ = { Day, Time ,Location, Activity and Incoming Call} }

Since, the dependency degree,

$\gamma(\mathbf{R_{41}},D) = \gamma(\mathbf{R_{42}},D) = \gamma(\mathbf{R_{44}},D) = \gamma(\mathbf{R_{31}},D)$,

$\gamma(\mathbf{R_{41}},D) = \gamma(\mathbf{R_{43}},D) = \gamma(\mathbf{R_{44}},D) = \gamma(\mathbf{R_{32}},D)$ and

$\gamma(\mathbf{R_{42}},D) = \gamma(\mathbf{R_{43}},D) = \gamma(\mathbf{R_{44}},D) = \gamma(\mathbf{R_{33}},D)$ and also

$R_{31} \subseteq R_{41}, R_{42}, R_{44}$,

$R_{32} \subseteq R_{41}, R_{43}, R_{44}$ and

$R_{33} \subseteq R_{41}, R_{43}, R_{44}$,

all the set of reducts with cardinality four can be discarded towards finding the core attributes. As a result the set of reducts with cardinality three was considered.

The **Set of Reducts with cardinality three =**

R_{31}= {Day, Time, Activity} ,

R_{32}= {Time, Location, Activity} and

R_{33} = {Time, Activity, Incoming Call} }

In R_{31} the attribute *Day* is D-dispensable in C because POS_{R31} (D) = POS(R_{31}{Day})(D)

In R_{32} the attribute *Location* is D-dispensable in C because POS_{R31} (D) = POS (R_{31}{Location})(D)

As a result the final set of reducts = {{Time, Activity}, {Time, Activity}, {Time, Activity, Incoming Call } }

i.e

Reducts with cardinality 3= {Time, Activity, IncomingCall}

&

The Minimal Reducts = { {Time, Activity} , {Time, Activity}}

Therefore ,

$CORE_D(C) = \cap Red_D(C) = \{ \{Time, Activity\}\}$ ----------(a)

The minimal attributes can also be determined using the discernibility function and discernibility matrix as illustrated in fig27 **:**

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
P1	ϕ															
P2	ϕ I	ϕ														
P3	ϕ	ϕ	ϕ													
P4	T,A,	T,A,I,	T,A,I,	ϕ												
P5	T,I	T,A,I,	T,I	A,I,	ϕ											
P6	T	T,A,I	T,I	A	ϕ	ϕ										
P7	T,A	T,A	T,A,I	T,A	ϕ	ϕ	ϕ									
P8	T,A,I	T,A	T,A	T,A,I	ϕ	ϕ	ϕ	ϕ								
P9	T,A	T,A,I	T,A,I	T,A	ϕ	ϕ	ϕ	ϕ	ϕ							
P10	T,A	T,A,I	T,A,I	T,A	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ						
P11	T,A,I	T,A	T,A,I	T,A,I	ϕ	ϕ	ϕ	ϕ	ϕ		ϕ					
P12	T,A,I	T,A,I	T,A,I	T,A,I	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ				
P13	T,A	T,A,I	T,A,I	T,A	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ			
P14	T,A,I	T,A	T,A	T,A,I	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ		
P15	T,A	T,A,I	T,A,I	T,A	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	
P16	T,A	T,A,I	T,A,I	T,A	T,A,I	T,A	T,A	T,A,I	T,A	T,A	T,A,I	T,A	T,A,I	T,A	T,A	ϕ

Fig 27: Discernibility Matrix

The discernibility function is

F(D,T,L,A,I) = (TVA) ∧ (TVI) ∧ (T) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVI) ∧ (TVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (AVI) ∧ (A) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVAVI) ∧ (TVA) ∧ (TVA)

= T ∧ A = Time and Activity

i.e $CORE_D(C)$ = **{ {Time, Activity}}** ----------**(b)**

From equation **a** and **b** it is clear that the core attribute are {{Time, Activity}**.**The resultant decision table obtained after reduction is as shown in the Table 29a**.** Similarly the decision table with the minimal reducts with cardinality 3 is {Time, Activity, IncomingCall} is shown in the Table29b**.**

Table 29a: Final Decision table with Minimal redacts of cardinality two

U	Condition Attributes		Decision Attributes
	Time	Activity	
p1	T_{v1}	A_{v1}	Dv1
P2	T_{v1}	A_{v2}	Dv1
P3	T_{v2}	A_{v3}	Dv2
P4	T_{v2}	A_{v1}	Dv3
P5	T_{v3}	A_{v4}	Dv3
P6	T_{v3}	A_{v5}	Dv3
P7	T_{v4}	A_{v6}	Dv3
P8	T_{v4}	A_{v7}	Dv3
P9	T_{v5}	A_{v8}	Dv4

Table29b: Final Decision table with Minimal reducts with cardinality three

U	Condition Attributes			Decision Attributes
	Time	Activity	Incoming Call	
p1	T_{v1}	A_{v1}	IC_{v1}	Dv1
P2	T_{v1}	A_{v2}	IC_{v2}	Dv1
P3	T_{v1}	A_{v1}	IC_{v2}	Dv1
P4	T_{v2}	A_{v3}	IC_{v1}	Dv2
P5	T_{v2}	A_{v1}	IC_{v3}	Dv3
P6	T_{v2}	A_{v1}	IC_{v1}	Dv3
P7	T_{v3}	A_{v4}	IC_{v1}	Dv3
P8	T_{v3}	A_{v5}	IC_{v2}	Dv3
P9	T_{v3}	A_{v5}	IC_{v1}	Dv3
P10	T_{v4}	A_{v6}	IC_{v1}	Dv3
P11	T_{v4}	A_{v6}	IC_{v2}	Dv3
P12	T_{v4}	A_{v6}	IC_{v3}	Dv3
P13	T_{v4}	A_{v7}	IC_{v1}	Dv3
P14	T_{v4}	A_{v7}	IC_{v2}	Dv3
P15	T_{v4}	A_{v6}	IC_{v1}	Dv3
P16	T_{v5}	A_{v8}	IC_{v1}	Dv4

In the presented work the decision table29a is used whenever there is context change without any incoming call**.** Decision Table29b can be used whenever there is change in context including the incoming call attributes**.**

The usage of the decision table in the place of rule base has shown the better performance in terms of storage as illustrated in Table30.

Table30 : Comparison of Decision Table and Rule base.

Table_ID	Table Size (No rows X Columns)
Rule Base(one month history)	*1345X10 = 13450*
Class Room Decision Table	*11X6 = 66*
Library Decision Table	*5X5 =25*
Staff Room Decision Table	*3X5 = 15*
Hostel Decision Table	*16 X5 = 80*

6.3.1.5.2 Experimental and Result Analysis: Following experiments was performed to realize the proposed system.

Experiment1: This experiment was conducted to determine the location based on the signal strength of nearest wifi access points. Table31 gives the list of wifi acces points along with their MAC address situated in the different location.

Table 31: MAC Address of Different Wifi Access points

Sl.NO	Device	Mac Address	Location
1	WifiAP1	001B1120AA8F	CLASS ROOM
2	WifiAP2	14D64D4DE19C	STAFF ROOM
3	WifAP3	BA66B5D1FB5	STAFF ROOM1
3	WifiAP4	14D64D4DE1A6	MTECH LAB
4	WifiAP5	001B1120ADD6	ADMIN
5	WifiAP6	001B11B061E9	LIBRARY
6	WifiAP7	00265A7206B9	MBA
7	WifiAP8	001B1120ADC8	CCF

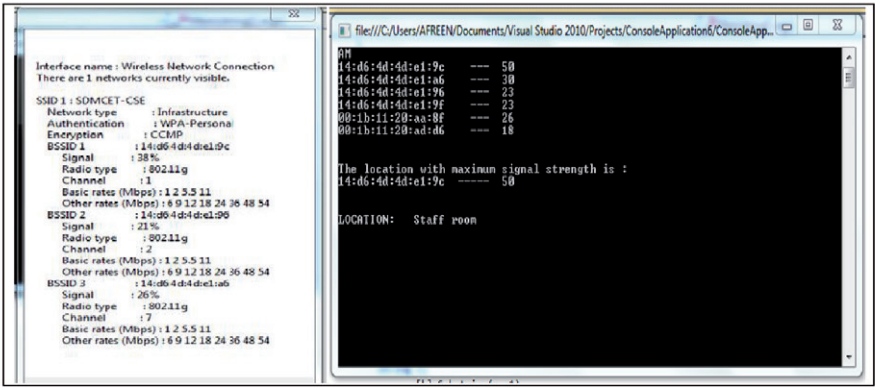


Fig28: Screen Shot of the MAC-addresses detected in "Staffroom"

In the Fig28 one can see that the location is actually “Staffroom” with (38/50)% signal strength which is the highest among others recognized. The Application will consider “Staffroom” as its location even though others are also recognized.

Experiment 2: This experiment was conducted to determine the average service popup time with respect to different locations. (X-axis= Location, Y-axis= Service Popup time in milli seconds (ms))

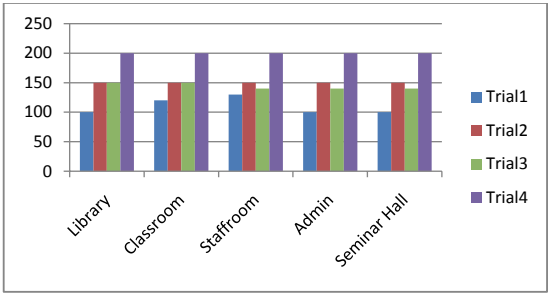


Fig 29: Service popup time of Applications in decision table based CAMP

Experiment 3: The experiment was aimed to evaluate the Precision of recommending the appropriate services and settings based on the current context of the user. About 20 users (students) were allowed to use the mobile in college campus in different locations. The result is highly subjective. Most users agree that the precession rate of 70-85 percent is useful.

$$\textbf{Precision=} \frac{N_{Useful}}{N_{Total}}$$

Where

N_{Useful} = No of services (Expected by the user$\cap$ Recommended by the System)

N_{Total} = No of Services (Recommended by the system$\cup$ Expected by the User)

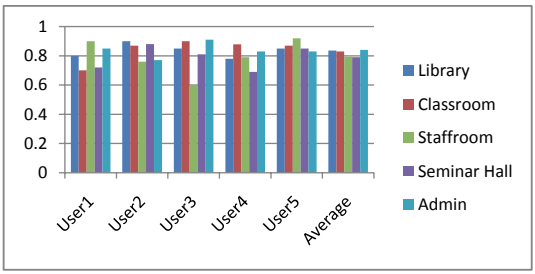


Fig 30 : Precision of service recommendation in different context in decision table based CAMP.

6.3.2. Conflict Resolution and Service Recommendation in Context Aware Environment with Multiple users and Single / Multiple Services.

Following algorithms are proposed for resolving conflict in the multiple user environments.

1. Fuzzy Bayesian Democratic Based Group Preference Algorithm (FBDGPA).
2. Fuzzy Rough Set Theory Based Group Conflict Resolving Algorithm (FRGCRA).

6.3.2.1 Fuzzy Bayesian Democratic Based Group Preference Algorithm (FBDGPA)

The algorithm is derived by considering the family as a group and Television as the Context Aware System. The family considered is the nuclear family with size of four members.The algorithm is developed to make the system aware of user as well as group of users. The algorithm is derived with following two goals:

1. To determine the user ratings for items making use of history (log) database of the system. (Here item may be service or settings like TV Volume, TV Brightness, TV Channel no, TV Program etc.)
2. To resolve the conflict and recommend a suitable service to group of users.

a) Determination of user rating for a given service: In order to achieve the first goal the algorithm makes use of Bayesian probability as discussed in the section 6.3.1.2. The user rating for each service for a given context is computed using the Bayesian Probability of the service for a given user context.

User Rating (UR) for a given service say S_i is given by the equation

$$UR(S_i) = \text{Bayesian Probability (Service/Context)}$$

$$= \frac{P\left(\frac{Context}{Service}\right) X\ P(Service)}{P(Context)}$$

The algorithm makes use of history database or log database of the system for computing the Bayesian Probability of the service. Table32 illustrates one sample Television call history database of user.

Table32: Example history database of Context Aware TV System

Sl.No	Day	Time	Mood	TV-Channel
1	Mon	Late Night	Normal	TV9
2	Mon	Late Night	Relaxed	TV7
3	Mon	Late Night	Relaxed	TV7
4	Mon	Late Night	Relaxed	TV7
5	Mon	Late Night	Happy	TV24
6	Mon	Late Night	Happy	TV24
7	Mon	Late Night	Normal	TV24
8	Mon	Late Night	Normal	TV24
9	Mon	Late Night	Relaxed	TV7
10	Mon	Late Night	Relaxed	TV7

The above example includes the following lists of contexts

C1: (Monday, LateNight, Normal)

C2: (Monday, LateNight, Relaxed)

C3: (Monday, LateNight, Happy)

The table33 illustrates the computed values of probabilities and Bayesian Probability of the respective context and actions

Table33: Computation of Bayesian Probability

Context	Services	P(Services)	P(Context/Service)	P(Context)	P(Service/Context)
C1	**TV9**	**1/10 =0.1**	**1/1=1**	**3/10=0.3**	**0.333333**
	TV7	**5/10 =0.5**	**0/5=0**		**0**
	TV24	**4/10 =0.4**	**2/4=0.5**		**0.66667**
C2	**TV9**	**1/10 =0.1**	**0/1=0**	**5/10=0.5**	**0**
	TV7	**5/10 =0.5**	**5/5=1**		**1**
	TV24	**4/10 =0.4**	**0/4=0**		**0**
C3	**TV9**	**1/10 =0.1**	**0/1=0**	**2/10=0.2**	**0**
	TV7	**5/10 =0.5**	**0/5=0**		**0**
	TV24	**4/10 =0.4**	**2/4=0.5**		**1**

From the above calculations it is clear that rating of user for a given service depends on the context**.** In the above illustration it is obvious that user prefers to watch TV7 during the context C2 and prefers to watch TV24 during context C1 and C3**.**

b) Conflict resolution and service recommendation: In order to achieve the second goal the research work considered a family TV viewing pattern as an example**.**

Family is a established group of members of mixed attributes like age, sex and role. Families may be small, big or joint families. Even though family is a small sized group but it is a source of multiple conflicts. The number of conflicts is directly proportional to number of social factors like family size, age differences, role differences, education, etc.

Consider a situation where in Father (F), Mother (M), Son(S) and Daughter (D) are watching TV. In such situation since Father is more dominant his preference will have more weightage as compared to the other (as per the survey on 50 Indian nuclear families). Fig 31 illustrates the member's hierarchy in different small families.

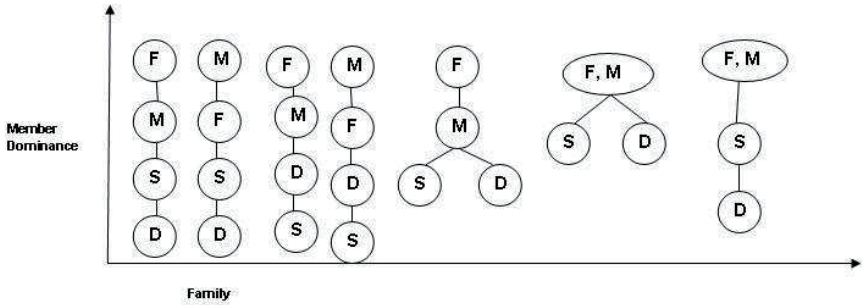


Fig31: Hierarchy of Family members

In most of the Indian families it is the member of the family with high dominance who resolves the conflict whenever conflict occurs. In the similar manner the algorithm is designed to consider the social dominance factor (SDF) of the member while resolving the conflict and recommending a service.

Social dominance factor (SDF) is a quantified value [0,1] representing the user dominance in a given family. The dominance of member depends on

i. The roles of the member say, Father, Mother, Son, Daughter, Grandfather, Grandmother, etc., i.e. Role Factor
ii. Family dependency on the member i.e. Family Dependency Factor and
iii. Age of the person i.e. Age Factor

i) Role Factor (RF): Each role of the family can be quantified in terms of role factor between [0,1]. The research presented in this thesis has considered role factor

(weight) value 1 for parents and 0.5 for children based on hierarchy. In most of the families it is the parents (Father, Mother or Both) who run the show. They are the source of love, affection, income and management. Naturally the entire family depends on them.

ii) Family Dependency Factor (FDF): The FDF is quantified to 0 or 1. FDF (member) =1 if the member is the source of income and FDF (member) =0 if he is not so.

iii) Age Factor (AF): In most of the families especially in India Grandfather and Grandmother will also live along with their children (even though nuclear families are becoming more popular nowadays). In such families preference and special respect will be given to such senior citizens. This relationship is quantified in terms of Age Factor (AF) which is computed based on their age as follows:

$$Af(x) = \begin{cases} 1 & if\ 50 < x < 100 \\ \frac{age(x)-10}{40} & if\ 10 < x < 50 \\ 0 & otherwise \end{cases}$$ ----------**6.3.2.1.a**

Social Dominance factor for a given member or user say $\mathbf{U_i}$ is computed using equation

SDF($\mathbf{U_i}$) = **Avg**(Role Factor + Family Dependency Factor + Age Factor)

----------**6.3.2.1.b**

Table34 illustrate one of the family with their social status, relationship and dominance (importance).

Table34: Social Relationships and dominance in a given Father dominant family

Sl.No	Role	Age	RF	FDF	AF	SDF(U_i)
U1	Father	40	1	1	0.75	0.91666
U2	Mother	35	1	0	0.625	0.51566
U3	Son	12	0.5	0	0.05	0.18333
U4	Daughter	07	0.5	0	0	0.16666

In real-time situations user preferences are truly influenced by the member surrounded by him at that moment of watching TV. Even though his /her personal choice is different many times user will compromise to the group preference. Sometimes because of group mood / behavior the person may get motivated to different mood and preferences. As a result the members individual ratings also

changes whenever they are in the group**.** User rating of any member for a given service in a group (GR) can be expressed in terms of personal rating (UR) and social influence (SDF). Equation below gives the relationship between user and family (group) influence.

$$GR_{ui}(S_i/Context) = UR_{ui}(Si/Context) * SDF(u_i) \quad \text{----------6.3.2.1.c}$$

Table35 illustrate the influence of Social Preference scores on their personal preference scores.

Table35: Influence of Group on individual

User	Role	Age	SDS(u_i)	UR_{ui}(P1)	UR_{ui}(P2)	UR_{ui}(P3)	GR_{ui}(P1)	GR_{ui}(P2)	GR_{ui}(P3)
Raj	Father	40	0.91666	50	40	10	45.83300	36.6664	9.1666
Sheela	Mother	35	0.51566	20	50	30	10.3132	25.783	15.469
Vinayak	Son	12	0.18333	30	30	40	5.4999	5.4999	7.3332
Palguni	Daughter	07	0.16666	40	40	20	6.666	6.666	3.3332

P1, P2, P3 are programs, UR is the respective user ratings

Equation 6.3.2.1.c represents the quantification of social and personal factors of individual family members in terms of user's group ratings (GR).Since the algorithm considers the social and personal factors of all the members of the family it is democratic in nature**.**

To measure the similarity between the user's interests in a family we have used Pearson Correlation Coefficient (PCC)**.** PCC can take the value between [-1 to +1]**.** Values near in the range [-1**,** 0] indicate the negative similarities and the values in the range [-1**,** 0] indicate the negative similarities and the values in the range [0**,** +1] indicates the positive similarity.

Based on the above discussions the research work has derived an algorithm to resolve conflict and recommend appropriate services for the group as illustrated in the figure 32.

Algorithm

Step1 : Retrieve the Current Context .

Step2 : For Each user
For Each service the preference score is calculated as follows:
URui (Service/Context) = Bayesian Probability (Service/Context)

Step3: Socially influenced ratings for each user is computed as follows

$$GR_{ui}(S_i/Context) = UR_{ui}(S_i/Context) * SDF(u_i)$$

Whereas
SDF(U_i) = **Avg**(Role Factor + FamilyDependency Factor + AgeFactor)

Step4: For each user
For each item

$$P_{(u,i)} = \overline{GR_u} + \frac{\sum_{v \in Nu}(GR_{v,i} - \overline{GR_v}) * Sim(u,v)}{\sum_{v \in N_u} |Sim(u,v)|}$$

Whereas

$$Sim(u,v) = \frac{\sum_{i \in Iuv}(GR_{u,i} - \overline{GR_u})(GR_{v,i} - \overline{GR_v})}{\sqrt{\sum_{i \in Iuv}(GR_{u,i} - \overline{GR_u})^2 \sum_{i \in Iuv}(GR_{v,i} - \overline{GR_v})^2}}$$

Step5: Conflict Degree $CD_{u,i\ i} = |(UR_{ui} - P_{(u,i)})|$

Step6: The Group conflict degree for a given item is calculated as
for service **i** = 1 to m determine the following

$$\mu_{u,i} = \frac{1}{n} \sum_{u=1}^{u=n} CD_{u,i}$$

Step7: Recommend *N* services with least conflicting scores as the *top* □ □*N* recommended set
. .

Note :

1. $\overline{GR_u}$ ***is average rating of user u in group for services.***

2. $P_{(u,i)}$ ***is the predicted rateof user u by the system for service i.***

3**. Sim(u,v)** is PCC which measures the similarity between two users u and v for service i

Fig32: Bayesian Probability based Conflict Resolving Algorithm

The **conflicting degree** (CD) used in the algorithm measures the amount of dissatisfaction or disagreement among different users with respect to the recommended services**.** It also measures the amount of dissatisfaction of individual user with respect to the service recommended by the system.

Example: Consider the four users say u1, u2, u3 and u4 with group ratings and system predicted ratings for three services S1, S2 and S3 as listed in the table36.Table36 includes the amount of individual and group conflict degree for three services. From the table36 it is evident that the service S1 has got least conflicting degree followed by service S2 and service S3. As a result the system recommends the service S1.

Table 36 : Group Rating (Assumed for illustration) and Predicted Ratings

User	$GR_{ui}(S1)$	$GR_{ui}(S2)$	$GR_{ui}(S3)$	$\overline{GR}_u$	$P(u,S_1)$	$P(u,S_2)$	$P(u,S_3)$
U_1	50	40	10	33.33	34.62297	42.0373	23.32577
U_2	25	45	30	33.33	34.56449	40.1018	25.32054
U_3	30	10	60	33.33	32.61422	25.36935	44.18602
U_4	30	15	55	33.33	30.3919	24.144	45.52571

Table 37 : Conflict Degree for different services

User	CD_{ui}(Service 1)	CD_{ui}(Service2)	CD_{ui}(Service3)
U_1	15.37703	2.0373	13.32577
U_2	9.56449	4.8982	4.67946
U_3	2.61422	15.36935	15.81398
U_4	0.3919	9.14400	9.47830
sum	27.95474	31.44885	43.29751
Average	6.98869	7.86221	10.82438

6.3.2.2 Case Study: Fuzzy Bayesian Democratic Based Context Aware TV Program and Settings Recommender.

In this section the usage of the proposed Fuzzy Bayesian Democratic Based Group Preference Algorithm is demonstrated by designing and developing Context Aware TV Program and Settings Recommender. The recommendation engine utilizes contextual parameters like personal, social, temporal, mood and activity. In addition to the contextual parameters the system utilizes the explicit or implicit user ratings and watching history to resolve the conflict if any while recommending the services.
A set of simulated sensors for detecting mood, activity, role, age, social dominance and set of real-time sensors like time, location and user identity (Bluetooth tags) are used in designing the system.
Table38 list the fuzzy values of the attributes like location, time, activity and mood considered in the research work.

Table38: Fuzzy Values for Example Sets

Fuzzy Value	SET
FV(Location)	SofaSet, Chair1, Chair2, Floor, Table1, Table2, Entrance, DiningTable.
FV(Time)	AM1, AM2, ------AM12, PM1------PM12, Early Morning, Morning, Afternoon, Forenoon, Evening, Night, Late Night.
FV(Activity)	Standing ,Sitting , Running ,Walking , Jogging , Eating , Talking ,Resting ,Sleeping ,Playing ,Reading ,Exercise ,
FV(Mood)	Happy,Normal,Relax,Cheerful,Deppressed,Excited,Disturbed,Comfort,Angry, Disturbed

TV will be monitoring continuously the context of its surroundings particularly that of users.

6.3.2.2.1 Architecture of the System: The architectural diagram of the proposed system is as shown in the figure33. The architecture includes context acquisition, context generation, conflict resolution, service recommendation and action generation. Initially the system generates the context by determining the time-date (using system clock) , mood, activity (using logical sensors i.e user stored profiles) and user identification using Bluetooth tags. The actions will be recommended by the recommendation engine making use of conflict resolution and service recommendation algorithm as discussed previously. The algorithm makes use of history database for determining the users rating using Bayesian probability. A snapshot of the history database used is given in the figure34.

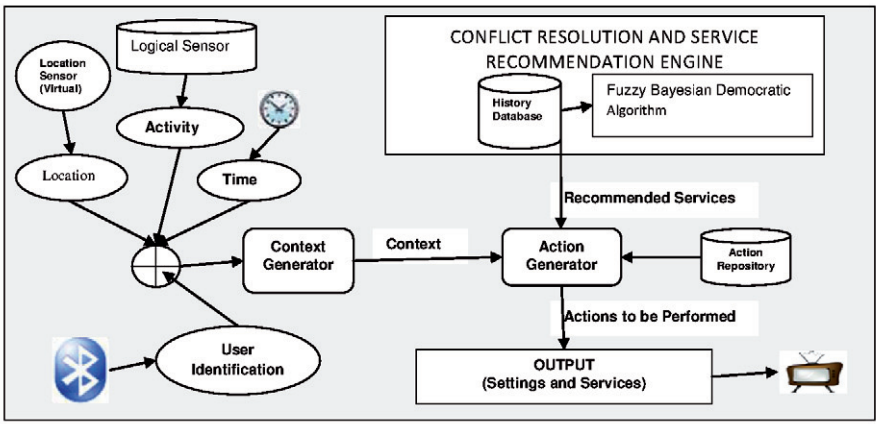


Fig 33: Architectural Diagram of Context Aware TV (CATV)

S-id	Loc	Date	Day	Time	Users	Activity	Mood	TV ch.No	Prg	Vol	C	B	Decision Attribute
S2	Lr	1-Dec	Thu	AM2	U1	sitting	N	T32	News	25	Def	Def	32N25DefDef
S3	Lr	1-Dec	Thu	AM3	U1	ing teeth/	N	Off	-	-	-	-	off
S4	Lr	1-Dec	Thu	AM4	U1	Sitting	N	T7	entern	25	Def	Def	7E25DefDef
S5	Lr	1-Dec	Thu	AM5	U1	ing breakf	N	Off	-	-	-	-	off
S21	Lr	1-Dec	Thu	PM13	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S22	Lr	1-Dec	Thu	PM14	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S23	Lr	1-Dec	Thu	PM15	U1	Sitting	N	T1	News	25	Def	Def	1N25DefDef
S24	Lr	1-Dec	Thu	PM16	U1	Sitting	N	T32	News	25	Def	Def	32N25DefDef
S2	Lr	2-Dec	Fri	AM2	U1	sitting	N	T33	News	25	Def	Def	33N25DefDef
S3	Lr	2-Dec	Fri	AM3	U1	ing teeth/	N	Off	-	-	-	-	off
S4	Lr	2-Dec	Fri	AM4	U1	Sitting	N	T7	entern	25	Def	Def	7E25DefDef
S5	Lr	2-Dec	Fri	AM5	U1	ing breakf	N	Off	-	-	-	-	off
S21	Lr	2-Dec	Fri	PM13	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S22	Lr	2-Dec	Fri	PM14	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S23	Lr	2-Dec	Fri	PM15	U1	Sitting	N	T1	News	25	Def	Def	1N25DefDef
S24	Lr	2-Dec	Fri	PM16	U1	Sitting	N	T32	News	25	Def	Def	32N25DefDef
S2	Lr	3-Dec	Sat	AM2	U1	sitting	N	T33	News	25	Def	Def	32N25DefDef
S3	Lr	3-Dec	Sat	AM3	U1	ing teeth/	N	Off	-	-	-	-	off
S4	Lr	3-Dec	Sat	AM4	U1	Sitting	N	T7	entern	25	Def	Def	7E25DefDef
S5	Lr	3-Dec	Sat	AM5	U1	ing breakf	N	Off	-	-	-	-	off
S20	Lr	3-Dec	Sat	PM13	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S21	Lr	3-Dec	Sat	PM14	U1	Resting	N	T20	Music	20	Def	Def	20M20DefDef
S22	Lr	3-Dec	Sat	PM15	U1	Sitting	N	T1	News	25	Def	Def	1N25DefDef
S23	Lr	3-Dec	Sat	PM16	U1	Sitting	N	T33	News	25	Def	Def	33N25DefDef
S6	Lr	4-Dec	Sun	AM6	U1	Sitting	N	T32	News	25	Def	Def	32N25DefDef
S22	Lr	4-Dec	Sun	PM13	U1	Sitting	N	T1	News	25	Def	Def	1N25DefDef

Fig34: A snapshot of the history database used in CATV

6.3.2.2.2 Experimental Set up: The experimental set up and the simulated TV that was used for experimental analysis is as shown in the figure 35. The system was developed using C# .NET for front end and MySQL database for back end. Fig 35a

to Fig35e shows the snapshots of simulated TV illustrating the actions recommended during different situations.

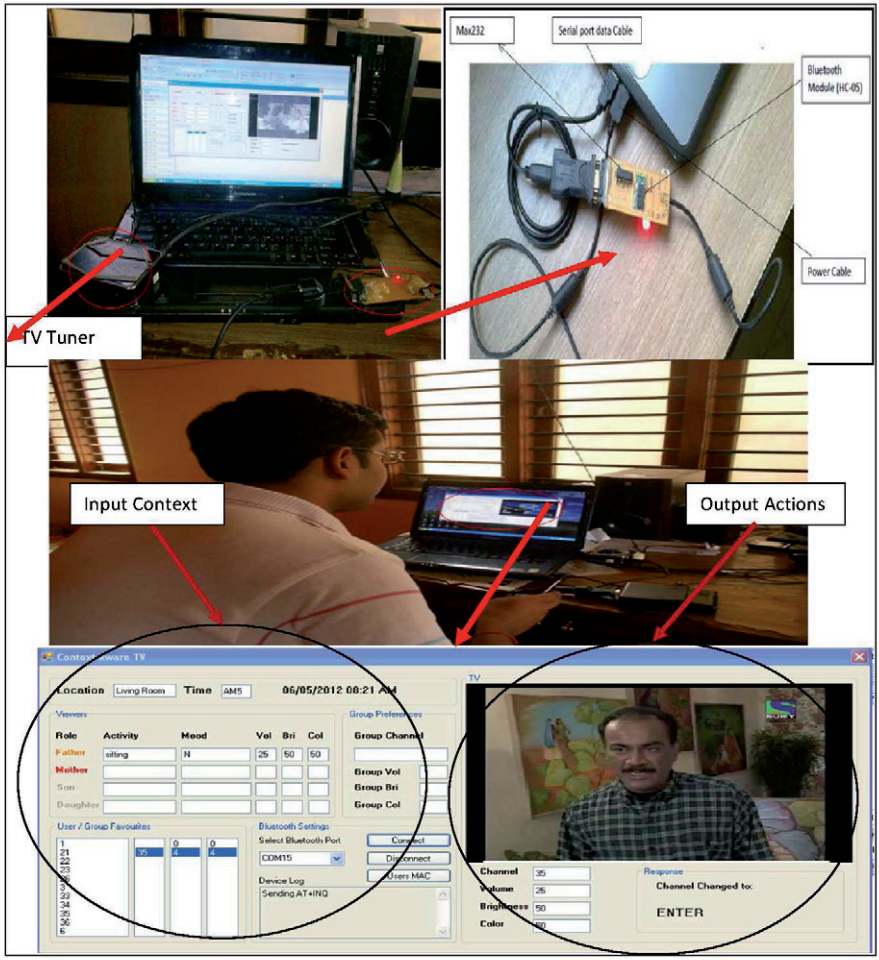


Fig35: Experimental Setup of CATV System

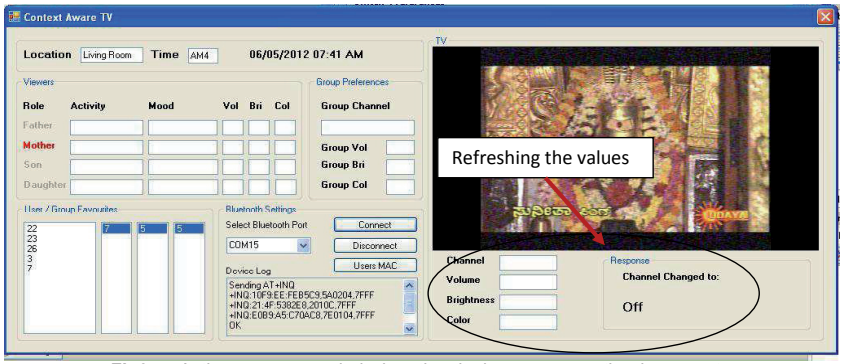


Fig35a: Actions recommended when the single user say mother is present.

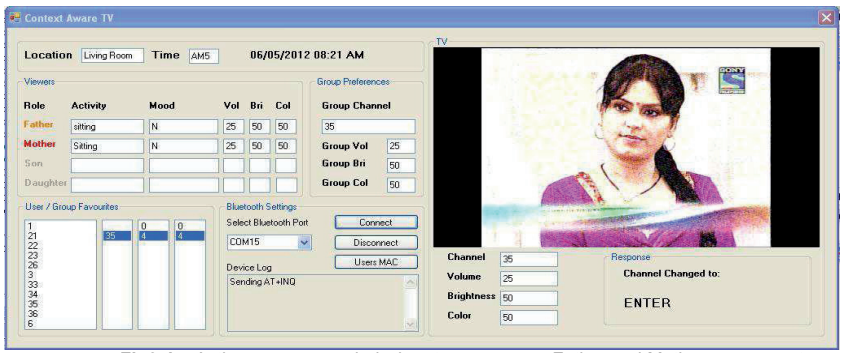


Fig35b : Actions recommended when two users say Father and Mother are present

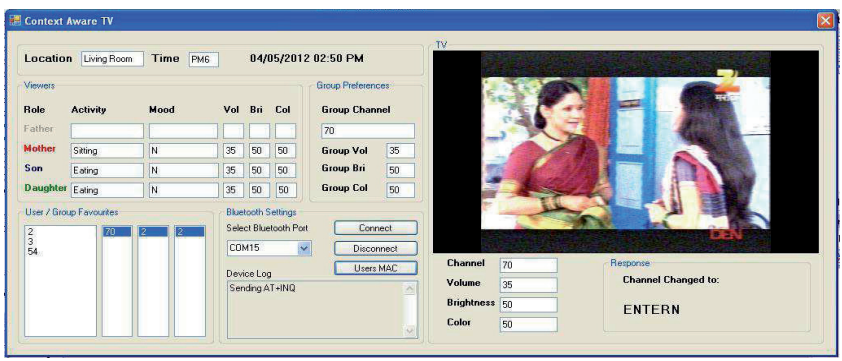


Fig35c: Actions Recommended When three users say Mother, Son and Daughter are watching TV.

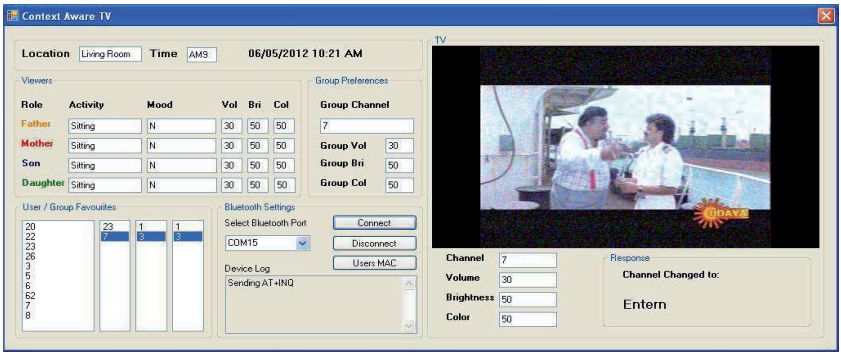


Fig35d: Actions Recommended When the entire family say Father, Mother, Son and Daughter are watching TV.

6.3.2.2.3 Experiment and Result Analysis Implementation: The proposed recommendation system was implemented making use of the simulated TV. A survey report of about 100 popular Indian Channels of different category was used for simulations. Activities and Mood was collected through interviewing (35 Small Indian Families) and observing closely the TV watching pattern of the three small families comprising Father, Mother, Son and Daughter (For about Six Months).

Experiment 1: This experiment was aimed to evaluate the precision of recommending the appropriate TV programs based on the current context of the family members. The average precision was calculated for every week. The recommendation precision was observed for entire 30 weeks. It was evaluated for three families. Table39 illustrates the watching pattern of three different families.

Table39: Family TV watching patterns.

Family	Frequency	Watching TVTime
Family1	Most Frequently	6-14hrs per day
Family2	Less Frequently	2 -6hr per day
Famly3	Highly irregular	0-14hrs per day

Fig36 shows the variation of precision with respect to week numbers. For all the families the recommendation accuracy increased smoothly. The system showed good performance for the family1 which had consistent watching pattern. However in the week between 11 and 13 the system recommendation performance was decreased sharply because of the sudden change in the watching pattern (due to

the world cup cricket).The maximum recommendation precision observed was 0.85,0.72 and 0.43 for family1, family2 and family3 respectively. Because of the poor relationship with TV the system showed very less precision for the family3.

$$\textbf{Precision} = \frac{\textit{The Number of programs family(member) actualy watched in each week}}{\textit{Total number of recomended programs in the given week}}$$

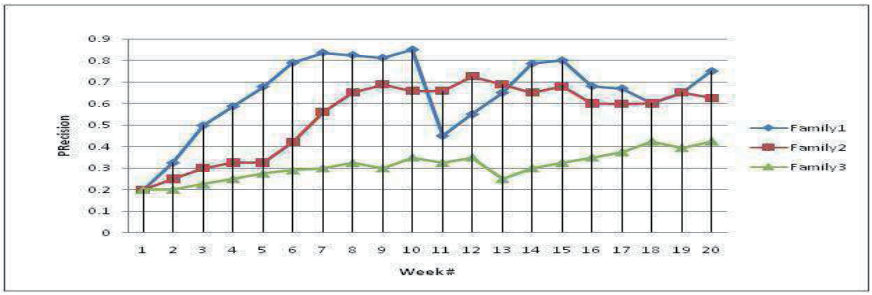


Fig36: Precision of CATV recommendation engine for 3 different families

Experiment 2: This experiment was aimed to evaluate the satisfaction levels of different users in different situations like watching TV individually and watching TV with the family members of family1, family2 and family3.

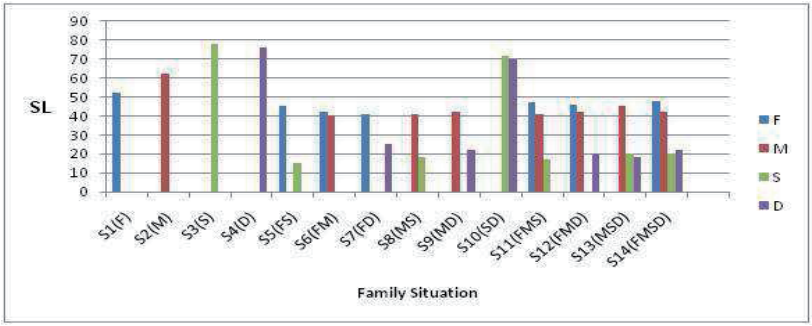


Fig37: Satisfaction level (SL) of Family1in different situations

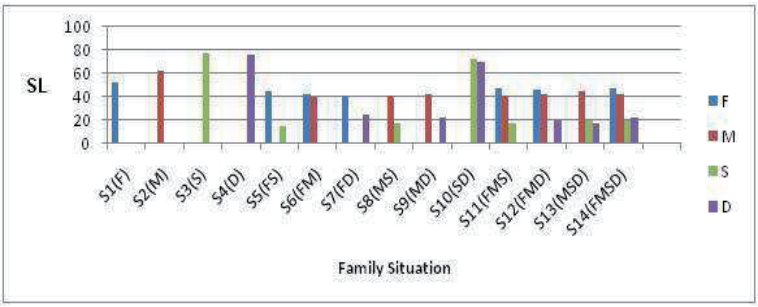


Fig38: Satisfaction level of Family2 in different situations

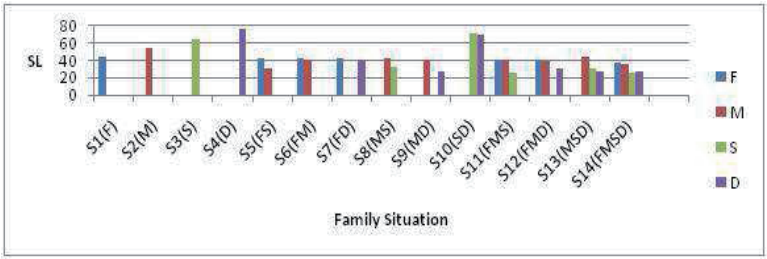


Fig39: Satisfaction level of Family3 in different situations

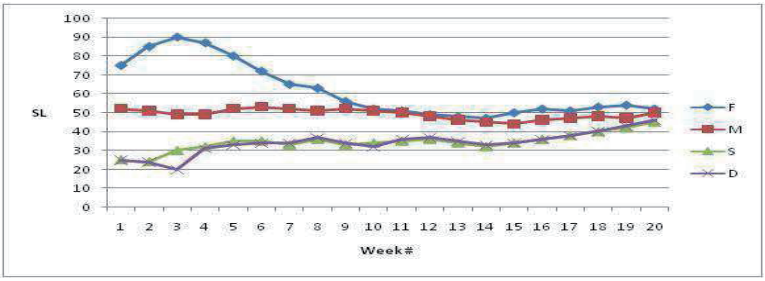


Fig40: Satisfaction level of F, M, S and D while watching TV together

The recommendation system even though initially it works in the favor of person with highest social dominant factor**.** But after certain amount of time period it works in the favor of entire family**.** Even though individual satisfaction level in a family decreases

but it reduces the verbal conflict among the members. Fig40 shows the relation between time and satisfaction level of different families.

Experiment3: This experiment was aimed to evaluate the performance of the recommendation system in terms of time and memory. The database used was MySQl. The time was measured using 1.73 GHZ CPU, 2GB RAM machine.

Table40 : Performance of CATV Recommendation System

Tasks	**Time**	**Storage**	**Memory Size required**
Context Searching and Matching	50ms	User profiles	320kb
Service Recommendation	10ms	Look up user profile	100kb
Individual Preference Calculation	2s -3s	Context repository	>1000kb
Group Preference Calculation	3s-5s	Watching history	>5000kb
Group Service Recommendation	1s	TV Content	500kb
Total	**6.06s to 9.06s**	**storage**	**>6920kb**

Experiment4: This experiment is survey based and it was aimed to understand the users watching pattern and to get the feedback on the proposed system. A survey of 35 small families comprising parents (Mother and Father) in the age of 35 to 45 and two children's in the age group of 5 to 15 was conducted. The Family considered for survey was healthy Middle class families having single TV positioned at the living room. The family was run by Father or Mother or Both. The children were going to school and belonged to LKG to 10^{th} class. For collecting Feedback of the proposed system the system was made used by different families with different TV watching patterns. Fig41 and Fig42 presents the report of survey made.

1. In your Family Who is More socially Dominant?
a. Father -80% **b**. Mother- 20% **c**.Son – 0% **d**.0%

2. What categories of the programs are viewed when the entire family is present?
a. Sports ---5 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---60%
c.Cartoons --5% **d**.News –28% **f.** Science and Education – 2%

3. What categories of the programs are viewed when only parents are present?
a.Sports ---5 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---65%
c.Cartoons --1% **d**.News –28% **e**. Science and Education – 1%

4. What categories of the programs are viewed when only children's are present?
a. Sports ---5 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---65%
c.Cartoons --1% **d**.News –28% **e**. Science and Education – 1%

5. What categories of the program mother wishes to watch when she is alone?
a.Sports ---1 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---77%
c.Cartoons --1% **d**.News –20% **e**. Science and Education – 1%

6. What categories of the program Father wishes to watch when he is alone?
a.Sports ---25% **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---40%
c.Cartoons --1% **d**.News –33% **e**. Science and Education – 1%

7. What categories of the programs are viewed by the children's in the age group of 5 to 10 years?
a. Sports ---1 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---20%
c.Cartoons --78% **d**.News –0% **e**. Science and Education – 1%

8. What categories of the programs are disliked by parents?
a.Sports ---10 % **b**.Entertainment (Movie/Music/Reality Shows/Serial) ---1%
c.Cartoons --70% **d**.News –5% **e**. Science and Education – 10%

9. What categories of the programs are disliked by children's?
a. Entertainment (Movie/Music/Reality Shows/Serial) ---20% **b**.Cartoons --0% **c.** Sports/ News /Science and Education – 80%

10. What categories of the programs are prevented to children's?
a. Adult Movies -100% (including horror movies)

11. How often the conflict arises in your family over TV programs while watching TV?
a. Always 3% b.Many Times **5**5% **c.** Rarely 40 % d. Not at all 2%

Fig41 : Questions Asked with Persons related to TV watching pattern

1. What rating you will give to the recommendation system based on its performance in resolving multi user conflict ?
a.Very Good -30% b.Good -50% c.Average -20% d. Not satisfactory -0%

2. What rating you will give to the recommendation system based on its performance in adapting to the different situations smoothly?
a.Very Good -10% b.Good -55% c.Average -20% d. Not satisfactory -0%

3. Did the recommendation system recommended wrong services?
a.Positive Answer-86% b.Negative Answer -10% c.Don't Know -4%

4. What rating you will give to the recommendation system based on its performance in helping you to make a satisfactory decision?
a. Good -80% b.Average -10% c. Not satisfactory -10% d. Don't Know-0%

5. What rating you will give to the recommendation system based on its overall performance ?
a.Very Good -15% b.Good -50% c.Average -20% d. Not satisfactory -15%

6..Did the recommendation system always favored the member with high social dominance?
a.Yes always-10% b.Not always -40% c. Judiciously -50% d.Don't know 0%

Fig42: Questions Asked related to TV recommendation System

6.3.2.3. Fuzzy Rough Set Theory Based Group Conflict Resolving Algorithm (FRGCRA)

The algorithm attempts to resolve the conflict among users and services making use of decision table. To determine the decision table the algorithm makes use of the history database containing the service usage pattern from the initial date to till date. The algorithm and basic concepts of the rough set theory is described in the section 6.3.1.3.

6.3.2.4 Case Study: Rough Set Theory Based User Aware TV Program and Settings Recommender

In this case study the recommendation engine of context aware TV is designed using decision table.

6.3.2.4.1 Architecture of the System: The architectural diagram of the proposed system is as shown in the figure43. The architecture includes context acquisition, context generation, decision rules selection and action generation.

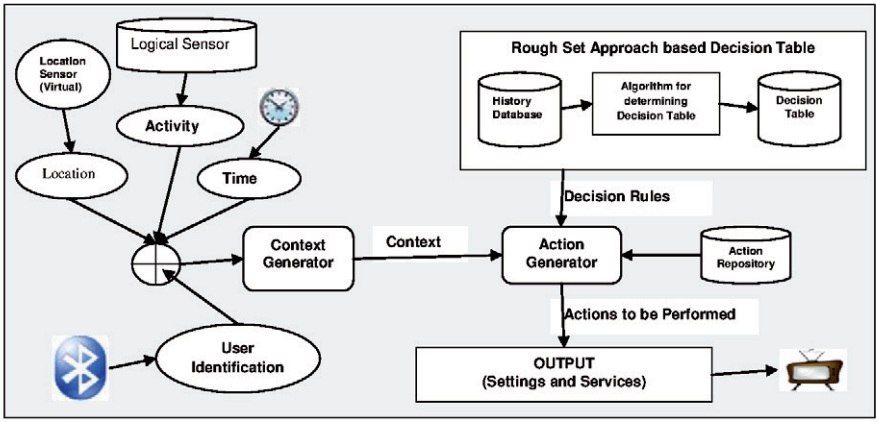


Fig 43: Architectural Diagram of decision table based Context Aware TV

Initially the system generates the context by determining the time-date (using system clock), user activity (using logical sensors i.e user stored profiles) and user identification using Bluetooth Tags. The actions will be recommended making use of

fuzzy rough set based decision table. The decision table is created making use of history database. History database is created by making use of users TV service usage log files for fixed period of time. The action recommender recommends the appropriate service based on the decision table.

6.3.2.4.2 Experimental and Result Analysis: The experimental set up and the simulated TV that was used to implement the proposed system is as shown in the figure 35.

Experiment1: This experiment was conducted to determine the final decision table for service recommendation. Table41 lists the different attributes (conditional and decision) and their symbolic notation used for designing the decision table.

Table41: Context Aware TV Information System

Context (C)	Allowable Choices	Settings and Services (D)
Location –Living Room	Sofa (L1)	1. Current Context info 2. Notifications 3. Volume 4. Color 5. Brightness 6. Channel 7. Program 8. Recommendations
	Chair1(L2)	
	Chair2(L3)	
	Floor (L4)	
	Table1(L5)	
	Table2(L6)	
	Entrance /Exit (L7)	
Time	AM1, AM2, ------AM12	
	PM1------PM12	
	Early Morning(EM)	
	Morning(M)	
	Afternoon(AN)	
	Forenoon,(FN)	
	Evening(EN)	
	Night(Nt)	
	Late Night(LN)	
Day	Working Day (WD)	
	Regular Day (RD)	
	Celebration Day (CD)	
Activity	Meeting	
	Working	
	Playing	
	Studying	
	Watching TV	
	Getting Ready	
	Lunch ,Dinner, Coffee	
Mood	Happy,Normal,Relax,Cheerful,Deppressed,Excited ,Disturbed,Comfort ,Angry, Disturbed	

For experimental purpose we selected a one month history database of a family with four members Father (F), Mother (M), Son (S) and Daughter (D). The history database was split into different small databases based on the Groups and individuals. As a result we obtained the databases for the following groups:
{G1={FMSD} , G2={FMS},G3={FMD}G4= {FSD} G5= { MSD} G6={FM} G7={FS} G8= {FD} G9= {MS} G10 = {MD} G11= {SD} G12 = { F} G13= {M} G14={S} G15={D} }.
Fig44 is a snapshot of one such group history database (say G1).

S-id	Loc	Date	Day	Time	Users	Activity	Mood	TV ch.No	Prg	Vol	C	B	Decision Attribute
S1	Lr	1-Dec	Thu	AM1	G1	ng, House	N	1	N	25	Def	Def	1N25DefDef
S29	Lr	1-Dec	Thu	PM21	G1	sitting	N	6	E	20	Def	Def	6E20DefDef
S30	Lr	1-Dec	Thu	PM22	G1	Sitting	N	6	E	20	Def	Def	6E20DefDef
S1	Lr	2-Dec	Fri	AM1	G1	ng, House	N	1	N	25	Def	Def	1N25DefDef
S29	Lr	2-Dec	Fri	PM21	G1	sitting	N	22	E	20	Def	Def	22E20DefDef
S30	Lr	2-Dec	Fri	PM22	G1	Sitting	N	6	E	20	Def	Def	6E20DefDef
S1	Lr	3-Dec	Sat	AM1	G1	ng, House	N	33	N	25	Def	Def	33N25DefDef
S24	Lr	3-Dec	Sat	PM17	G1	Sitting	N	23	E	20	Def	Def	23E20DefDef
S28	Lr	3-Dec	Sat	PM21	G1	sitting	N	6	E	20	Def	Def	6E20DefDef
S29	Lr	3-Dec	Sat	PM22	G1	Sitting	N	23	E	20	Def	Def	23E20DefDef
S5	Lr	4-Dec	Sun	AM5	G1	sitting	N	3	E	25	Def	Def	3E25DefDef
S26	Lr	4-Dec	Sun	PM17	G1	Sitting	N	26	E	20	Def	Def	26E20DefDef
S30	Lr	4-Dec	Sun	PM21	G1	Sitting	N	21	M	20	Def	Def	21M20DefDef
S31	Lr	4-Dec	Sun	PM22	G1	Sitting	N	21	M	20	Def	Def	21M20DefDef
S1	Lr	5-Dec	Mon	AM1	G1	ng, House	N	33	N	25	Def	Def	33N25DefDef
S29	Lr	5-Dec	Mon	PM21	G1	sitting	N	6	E	20	Def	Def	6E20DefDef
S30	Lr	5-Dec	Mon	PM22	G1	Sitting	N	6	E	20	Def	Def	6E20DefDef
S1	Lr	6-Dec	Tue	AM1	G1	ng, House	N	1	N	25	Def	Def	1N25DefDef
S29	Lr	6-Dec	Tue	PM21	G1	sitting	N	22	E	20	Def	Def	22E20DefDef
S30	Lr	6-Dec	Tue	PM22	G1	Sitting	N	6	E	20	Def	Def	6E20DefDef
S1	Lr	7-Dec	Wed	AM1	G1	ng, House	N	33	N	25	Def	Def	33N25DefDef
S29	Lr	7-Dec	Wed	PM21	G1	sitting	N	23	E	20	Def	Def	23E20DefDef
S30	Lr	7-Dec	Wed	PM22	G1	Sitting	N	6	E	20	Def	Def	6E20DefDef
S1	Lr	8-Dec	Thu	AM1	G1	ng, House	N	1	N	25	Def	Def	1N25DefDef
S29	Lr	8-Dec	Thu	PM21	G1	sitting	N	6	E	20	Def	Def	6E20DefDef

Fig44: History database of Group G1 {Father, Mother, Son, Daughter}

For each above tables (i.e G1, G2, G3, -------G15} the decision table was constructed by determining the core attributes in the similar manner as discussed in the section 6.3.1.3 and 6.3.1.5. It was found that the set of attributes { {Day, Time, Activity,}} is the set of core attributes or reducts.
Fig45 is the snapshot of history database of single user (U4) viewing pattern and Fig46 is the decision table obtained after applying the rough set theory concepts. Table in Fig46 is obtained by applying the FRGCR algorithm and also by making use of ROSETTA Software Tool with embedded Johnson's algorithm.

S-id	Loc	Date	Day	Time	Users	Activity	Mood	Decision Attribute
S16	Sofa	3-Dec	Sat	PM5	U4	Resting,	N	off
S11	Chair	4-Dec	Sun	AM11	U4	sitting	N	24S30DefDef
S12	Chair	4-Dec	Sun	AM12	U4	Sitting	N	25S30DefDef
S13	Chair	4-Dec	Sun	PM1	U4	Sitting	N	24S30DefDef
S16	Sofa	10-Dec	Sat	PM5	U4	Resting,	N	off
S11	Chair	11-Dec	Sun	AM11	U4	sitting	N	24S30DefDef
S12	Chair	11-Dec	Sun	AM12	U4	Sitting	N	56S30DefDef
S13	Chair	11-Dec	Sun	PM1	U4	Sitting	N	24S30DefDef
S16	Sofa	17-Dec	Sat	PM5	U4	Resting,	N	off
S11	Chair	18-Dec	Sun	AM11	U4	sitting	N	24S30DefDef
S12	Chair	18-Dec	Sun	AM12	U4	Sitting	N	56S30DefDef
S13	Chair	18-Dec	Sun	PM1	U4	Sitting	N	24S30DefDef
S16	Sofa	24-Dec	Sat	PM5	U4	Resting,	N	off
S11	Chair	25-Dec	Sun	AM11	U4	sitting	N	24S30DefDef
S12	Chair	25-Dec	Sun	AM12	U4	Sitting	N	57S30DefDef
S13	Chair	25-Dec	Sun	PM1	U4	Sitting	N	25S30DefDef
S10	Chair	31-Dec	Sat	AM11	U4	Sitting	N	2C35DefDef

Fig45 : A snapshot of the Database of a single user say (u4) TV Viewing pattern.

Day	Time	Activity	Decision Attribute
Sat	PM5	Resting,	off
Sun	AM11	sitting	24S30DefDef
Sun	AM12	Sitting	25S30DefDef
Sun	PM1	Sitting	24S30DefDef
Sat	PM5	Resting,	off
Sun	AM11	sitting	24S30DefDef
Sun	AM12	Sitting	56S30DefDef
Sun	PM1	Sitting	24S30DefDef
Sat	PM5	Resting,	off
Sun	AM11	sitting	24S30DefDef
Sun	AM12	Sitting	56S30DefDef
Sun	PM1	Sitting	24S30DefDef
Sat	PM5	Resting,	off
Sun	AM11	sitting	24S30DefDef
Sun	AM12	Sitting	57S30DefDef
Sun	PM1	Sitting	25S30DefDef
Sat	AM11	Sitting	2C35DefDef

Fig46 : Decision Table for the database (Fig45) with Core Attributes {Day,Time ,Activity}

Experiment 2: This experiment was aimed to evaluate the performance of the recommendation system in terms of time and memory. The database used is MS Access .The time was measured using 1.73 GHZ CPU, 2GB RAM machine. The facts in table42 illustrates that performance of RST based Decision Table is better than the performance of Bayesian probability.

Table42: Performance of System

Tasks	**Time With Bayesian**	**Time with Rough set**	**Database**	**Memory Size required**
Context Searching and Matching	50ms	10ms to 50ms	User profiles	320kb
Service Recommendation	10ms	10ms	Look up user profile	100kb
Individual Preference Calculation	3s-4s	Not Applicable	Context repository	>1000kb
Group Preference Calculation	3s-5s	Not Applicable	Watching history	>5000kb
Group Service Recommendation	1s	Not Applicable	TV Content	500kb
Total	**7.06s to10.06s**	**20ms to 60ms**	**Storage**	**>6920kb**

Experiment 3: This experiment was aimed to evaluate the precision of recommending the appropriate TV programs based on the current context of the family members. Fig47 illustrates that the precision performance shown by the system based on the Fuzzy Bayesian Democratic Group Preference Algorithm and Fuzzy Rough Set theory based Group Conflict Resolving Algorithm. It is evident from the graph that both the algorithm shows almost similar performance in terms of precision of recommendation of the appropriate TV programs.

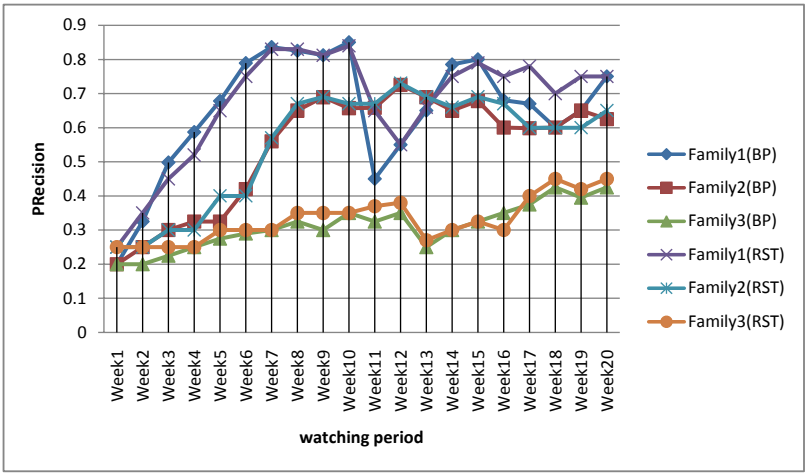


Fig 47: Precision of the System in Service Recommendation

7. Conclusion

The research work presented in this thesis introduces generic methodologies to design a personally and socially acceptable context aware system. With the objective of introducing a novel approaches, the research work has addressed the following issues: **1)** Modeling user context and **2)** User Context based Conflict resolution and Service Recommendation. Major Contributions of the research work reported in this thesis are:

- Modeling user context using CEAR Diagram with very good understandability, expressiveness and completeness.
- Algorithms to resolve conflict by integrating the social, personal and democratic factors with AI tools like rule base, fuzzy Bayesian probability and rough set theory.
- A novel design of recommendation engine utilizing the contextual parameters like personal, temporal, social, activity, mood and schedule agendas in addition to the user ratings for the service.

The usage of the proposed context model and algorithms is demonstrated in developing applications like Context Aware TV and Context Aware Mobile Phone. In context aware TV, *recommendation precision* for **FBDGPA** and **FRGCRA** algorithms, observed was in the range of **0.25-0.85**, **0.2-0.72** and **0.2-0.43** for family1, family2 and family3 users respectively. Because of the poor relationship with TV the system showed very less precision for the family3 users. In case of context aware mobile the result was highly subjective. Most users agreed that the precession rate of **FRBA** algorithm of **76-82** percent and the precession rate of **FDTBA** algorithm of **70 -85** percent was useful.

As a future work the research work can be extended, to propose a modeling of dynamic context for a given entity (say user) by applying the concepts of situation calculus and the proposed context model. There is a scope to introduce the following: a dedicated context oriented programming language, a series of protocols to establish communication among ubiquitous context aware entities and a generic toolkit for design and developing context aware applications. In addition the proposed algorithms can be customized and used for the development of different applications like context aware automobiles, context aware gadgets (other than TV and Mobile), context aware home, context aware meeting room, context aware class room, etc .

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Annexure1: List of Publications out of Thesis

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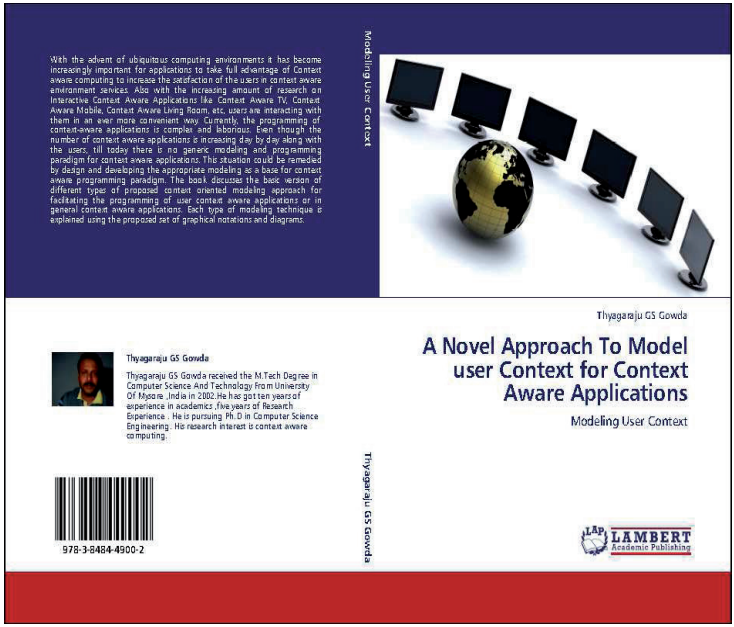
Annexure2: Book Published based on part of the Research Work



Book titled
"***A Novel Approach To Model User Context for Context Aware Applications***"**,**
(*Sub title : Modeling User Context***),**
is published by
Publisher **:**LAP LAMBERT Academic Publishing, Germany, https://www.lap-publishing.com/ ,ISBN:978-3-8484-4900-2,April-2012.

Amazonweblink: http://www.amazon.com /Novel-Approach-Model-Context-Applications/dp/3848449005/ref=sr_1_ fkmr1_1? s=books&ie=UTF8&qid = 1334976420&sr =1-1-fkmr1 , Publication Date :11-04-2012,No Of Pages **:** 204 **,**

More book Link : https://www.morebooks.de /store/gb/book/a-novel-approach-to-model-user-context-for-context-aware-applications/ isbn / 978-3-8484-4900-2.

Annexure3: Modeling of User Context using Markup Language

1. Modeling Single User Context

```
<?xml version="1.0" ?>
<! DOCTYPE User Context >
<Context_Location="Home"Generator="CATV" >
<SingleUser_Context >
        <User>
            <Generator = Profile Database in CATV>
           <NameUID="731219-xxxxx" >Raju</Name>
        </User>
        <User Role >
            <Generator = Profile Database in CATV>
            <Role = Son>
        < /User Role>
        <User Priority>
          <Generator = Profile Database in CATV>
          < Priority = Low>
        </User Priority>
        <Location>
                <Generator = Location Sensor _Embedded in CATV>
                 <Location Type="Living Room">
                    <Generator = Pressure Sensor Embedded in Sofa>
                        <Sub Location Type = “Sofa”>
                     </Sub Location>
         </Location>
         <Time>          <Generator = Time Sensor>
          <Interval Type="Absolute" >
                  <From>2012, 04, 12,21.30</From>
                  <To>2012, 04, 12, 21.31</To>
        </Interval>
        </Time>
         <Activity>
                 <Generator = Pressure Sensor Embedded in Sofa>
            < Activity Type = “Sitting on Sofa”>
          </Activity>
         <Mood>
             <Generator = Emotion Sensor embedded in CATV>

           <Mood Type = “Relaxed”>
        </Mood>
   <Intention >
         <Generator = History Database stored in CATV>
```

```
                <Intention Type = “Watching TV” >
                <Interest Type = “ Channel 9”>
                </Interest>
            <Intention>
</Single User Context>
```

2. Modeling Multi User Context

```
<?xml version="1.0" ?>
<!DOCTYPE Multi_User Context >
<Context_Location="Home"Generator="CATV" >
<MultiUser_Context >
        <Group GID =1 ><Type = Family>
            <Group Size= 4 > <Generator = User Sensors Embedded in CATV>
              <User1>
                    <Generator = Profile Database in CATV>
                  <NameUID="731219-xxxxx" >Raju</Name>
              </User1>
              <User1 Role >
                    <Generator = Profile Database in CATV>
                    <Role = Son>
              < /User1 Role>
              <User1 Priority>
                      <Generator = Profile Database in CATV>
                      < Priority = Low>
              </User Priority>
              <User1_Location>
                 <Generator = Location Sensor _Embedded in CATV>
                  <Location Type="Living Room">
                     <Generator = Pressure Sensor Embedded in Sofa>
                         <Sub Location Type = “Sofa”>
                         </Sub Location>
                 </Location>
              <User1_Time>   <Generator = Time Sensor>
                 <Interval Type="Absolute" >
                         <From>2012, 04, 12,21.30</From>
                         <To>2012, 04, 12, 22.30</To>
                </Interval>
              </User1_Time>
                <User1_Activity>
                   <Generator = Pressure Sensor Embedded in Sofa>
                    < User1_Activity Type = “Sitting on Sofa”>
                </User1_Activity>
              <User1_Mood>
                <Generator = Emotion Sensor embedded in CATV>
```

```
                <USer1_Mood Type = “Relaxed”>
              </User1_Mood>
             <User1_Intention >
                 <Generator = History Database stored in CATV>
                   < User1_Intention Type = “Watching TV” >
                   < User1_Interest Type = “ Channel 9”>
                    </ User1_Interest>
               < /User1_Intention>

             <User2>
                        <Generator = Profile Database in CATV>
                      <NameUID="631210-xxxxx" >Palguni</Name>
              </User2>
              <User2 Role >
                        <Generator = Profile Database in CATV>
                        <Role = Daughter>
             < /User2 Role>
         <User2 Priority>
                           <Generator = Profile Database in CATV>
                           < Priority = Low>
        </User Priority>
        <User2_Location>
                  <Generator = Location Sensor _Embedded in CATV>
                   <User2_Location Type="Living Room">
                      <Generator = Pressure Sensor Embedded in Chair>
                           <USer2_Sub Location Type = “Chair#2”>
                           </User2_Sub Location>
                 </User2_Location>
         <User2_Time>   <Generator = Time Sensor>
                  <Interval Type="Absolute" >
                           <From>2012, 04, 12,21.31</From>
                           <To>2012, 04, 12, 22.30</To>
                 </Interval>
        </User2_Time>
         <User2_Activity>
                  <Generator = Pressure Sensor Embedded in Chair#2>
             < User2_Activity Type = “Sitting on Chair#2”>
          </User2_Activity>
         <User2_Mood>
              <Generator = Emotion Sensor embedded in CATV>
             <USer2_Mood Type = “Normal”>
        </User2_Mood>
<User2_Intention >
        <Generator = History Database stored in CATV>
           < User2_Intention Type = “Watching TV” >
           < User2_Interest Type = “Pogo TV”>
          </ User2_Interest>
        < User2_Intention>
```

```
<User3>
                <Generator = Profile Database in CATV>
              <NameUID="731219-xxxxx" >Rahul</Name>
        </User3>
        <User3 Role >
                <Generator = Profile Database in CATV>
                <Role = Father>
        < /User3 Role>
      <User3 Priority>
                    <Generator = Profile Database in CATV>
                    < Priority = High>
     </User Priority>
     <User3_Location>
           <Generator = Location Sensor _Embedded in CATV>
            <User3_Location Type="Living Room">
              <Generator = Pressure Sensor Embedded in Sofa>
                    <User3_Sub Location Type = “Sofa”>
                    </User3_Sub Location>
           </User3_Location>
     <User3_Time>   <Generator = Time Sensor>
           <Interval Type="Absolute" >
                    <From>2012, 04, 12, 21.31</From>
                    <To>2012, 04, 12, 22.30</To>
         </Interval>
     </User3_Time>
     <User3_Activity>
           <Generator = Pressure Sensor Embedded in Sofa>
       < User3_Activity Type = “Sitting on Sofa”>
      </User3_Activity>
     <User3_Mood>
        <Generator = Emotion Sensor embedded in CATV>
       <USer3_Mood Type = “Relaxed”>
     </User3_Mood>
<User3_Intention >
      <Generator = History Database stored in CATV>
        < User3_Intention Type = “Watching TV” >
        < User3_Interest Type = “ News24 Channel”>
       </ User3_Interest>
     < User3_Intention>

     <User4>
                <Generator = Profile Database in CATV>
              <NameUID="731219-xxxxx" >Ramya</Name>
        </User4>
        <User4Role >
                <Generator = Profile Database in CATV>
```

```
                    <Role = Mother/Wife>
                < /User4Role>
            <User4 Priority>
                        <Generator = Profile Database in CATV>
                        < Priority = Medium>
            </User4 Priority>
            <User4_Location>
                    <Generator = Location Sensor _Embedded in CATV>
                     <Location Type="Living Room">
                        <Generator = Pressure Sensor Embedded in Sofa>
                            <Sub Location Type = “Chair#2”>
                            </Sub Location>
                     </Location>
            <User4_Time>   <Generator = Time Sensor>
                     <Interval Type="Absolute" >
                            <From>2012, 04, 12, 21.32</From>
                            <To>2012, 04, 12, 22.30</To>
                    </Interval>
            </User4_Time>
            <User4_Activity>
                     <Generator = Pressure Sensor Embedded in Sofa>
                < User4_Activity Type = “Sitting on Chair#2”>
             </User4_Activity>
            <User4_Mood>
                 <Generator = Emotion Sensor embedded in CATV>
                <USer4_Mood Type = “Happy”>
            </User4_Mood>
        <User4_Intention >
             <Generator = History Database stored in CATV>
                 < User4_Intention Type = “Watching TV” >
                 < User4_Interest Type = “ Channel 10”>
                </ User4_Interest>
            < User4_Intention>
</Multi_User Context>
```

Annexure4: A Sample History Database Used in CATV

S-id	Loc	Date	Day	Time	Users	Activity	Mood	TV ch.No	Prg	Vol	B	Decision Attribute
S2	Lr	1-Dec	Thu	AM2	U1	sitting	N	T32	News	25	Def	32N25DefDef
S3	Lr	1-Dec	Thu	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	1-Dec	Thu	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	1-Dec	Thu	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	1-Dec	Thu	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	1-Dec	Thu	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	1-Dec	Thu	PM15	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S24	Lr	1-Dec	Thu	PM16	U1	Sitting	N	T32	News	25	Def	32N25DefDef
S2	Lr	2-Dec	Fri	AM2	U1	sitting	N	T33	News	25	Def	33N25DefDef
S3	Lr	2-Dec	Fri	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	2-Dec	Fri	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	2-Dec	Fri	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	2-Dec	Fri	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	2-Dec	Fri	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	2-Dec	Fri	PM15	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S24	Lr	2-Dec	Fri	PM16	U1	Sitting	N	T32	News	25	Def	32N25DefDef
S2	Lr	3-Dec	Sat	AM2	U1	sitting	N	T33	News	25	Def	32N25DefDef
S3	Lr	3-Dec	Sat	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	3-Dec	Sat	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	3-Dec	Sat	AM5	U1	Having breakfast	N	Off	-	-	-	off
S20	Lr	3-Dec	Sat	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S21	Lr	3-Dec	Sat	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	3-Dec	Sat	PM15	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S23	Lr	3-Dec	Sat	PM16	U1	Sitting	N	T33	News	25	Def	33N25DefDef
S6	Lr	4-Dec	Sun	AM6	U1	Sitting	N	T32	News	25	Def	32N25DefDef
S22	Lr	4-Dec	Sun	PM13	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S23	Lr	4-Dec	Sun	PM14	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S24	Lr	4-Dec	Sun	PM15	U1	Sitting	N	T22	Entern	30	Def	22E30DefDef
S25	Lr	4-Dec	Sun	PM16	U1	Sitting	N	T20	Music	30	Def	20M30DefDef
S2	Lr	5-Dec	Mon	AM2	U1	sitting	N	T1	News	25	Def	1N25DefDef
S3	Lr	5-Dec	Mon	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	5-Dec	Mon	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef

S5	Lr	5-Dec	Mon	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	5-Dec	Mon	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	5-Dec	Mon	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	5-Dec	Mon	PM15	U1	Sitting	N	T34	News	25	Def	34N25DefDef
S24	Lr	5-Dec	Mon	PM16	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S2	Lr	6-Dec	Tue	AM2	U1	sitting	N	T33	News	25	Def	33N25DefDef
S3	Lr	6-Dec	Tue	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	6-Dec	Tue	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	6-Dec	Tue	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	6-Dec	Tue	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	6-Dec	Tue	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	6-Dec	Tue	PM15	U1	Sitting	N	T34	News	25	Def	34N25DefDef
S24	Lr	6-Dec	Tue	PM16	U1	Sitting	N	T32	News	25	Def	32N25DefDef
S2	Lr	7-Dec	Wed	AM2	U1	sitting	N	T1	News	25	Def	1N25DefDef
S3	Lr	7-Dec	Wed	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	7-Dec	Wed	AM4	U1	Sitting	N	T26	entern	25	Def	26E25DefDef
S5	Lr	7-Dec	Wed	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	7-Dec	Wed	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	7-Dec	Wed	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	7-Dec	Wed	PM15	U1	Sitting	N	T32	News	25	Def	32N25DefDef
S24	Lr	7-Dec	Wed	PM16	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S2	Lr	8-Dec	Thu	AM2	U1	sitting	N	T33	News	25	Def	33N25DefDef
S3	Lr	8-Dec	Thu	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	8-Dec	Thu	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	8-Dec	Thu	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	8-Dec	Thu	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	8-Dec	Thu	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	8-Dec	Thu	PM15	U1	Sitting	N	T34	News	25	Def	34N25DefDef
S24	Lr	8-Dec	Thu	PM16	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S2	Lr	9-Dec	Fri	AM2	U1	sitting	N	T1	News	25	Def	1N25DefDef
S3	Lr	9-Dec	Fri	AM3	U1	Brushing teeth/bath	N	Off	-	-	-	off
S4	Lr	9-Dec	Fri	AM4	U1	Sitting	N	T7	entern	25	Def	7E25DefDef
S5	Lr	9-Dec	Fri	AM5	U1	Having breakfast	N	Off	-	-	-	off
S21	Lr	9-Dec	Fri	PM13	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S22	Lr	9-Dec	Fri	PM14	U1	Resting	N	T20	Music	20	Def	20M20DefDef
S23	Lr	9-Dec	Fri	PM15	U1	Sitting	N	T1	News	25	Def	1N25DefDef
S24	Lr	9-Dec	Fri	PM16	U1	Sitting	N	T32	News	25	Def	32N25DefDef

Glossary

Ubiquitous Computing: It is a model of human-computer interaction**,** in which information processing has been thoroughly integrated into everyday objects and activities**.**

Context Aware Computing: A computing methodology which embeds the context aware capabilities into computing system to provide the context aware services.

User Context: A set of information that characterizes the situation of user partially or completely.

Socialization: A general definition is to make someone that behave in a way that is acceptable to society.

Personalization: Personalization is understanding the needs of each individual and helping satisfy a goal that efficiently and knowledgeably addresses each individual's need in a given context.

Conflict: Conflict in context aware ubicomp environment is defined as the degree of disagreement or discomfort between user's interests with respect to the services recommended by the context aware application**.**

Fuzzy Logic: Fuzzy logic is a form of many –valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact.

Context Aware Mobile Phone (CAMP): A mobile phone which changes its settings and services as per the situation of user or owner of the mobile.

Context Aware Television (CATV): A television which provides the services based on the personal and social situation of the users.

Bluetooth Technology : Is standardized as IEEE 802.15.1 is a wireless technology standard for exchanging data over short distances (using short wavelength radio transmissions in the ISM band from 2400 -2480 MHZ) from fixed and mobile devices , creating personal area networks (PANs) with high levels of security.

Bluetooth Access Point*:* It is a device that allows wireless communication devices to connect to the wireless network through them by using the Bluetooth technology

MAC Address*:* stands for Media Access Control address. It is a unique identifier assigned by the manufacturer to Bluetooth Access *Point,* network interface cards (NICs) or network adapters, and it is known as the physical address.

WIFI: Wireless Fidelity, A wireless local area network that uses high frequency radio signals to transmit and receive data over distances of a few hundred feet, uses Ethernet protocol