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## INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/17917

DOI URL: <http://dx.doi.org/10.21474/IJAR01/17917>



### RESEARCH ARTICLE

#### MOVING FROM INFORMAL INTERACTION TO FOCUSED KNOWLEDGE SHARING AMONG USERS IN AN AGENT-BASED LEARNING ENVIRONMENT

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#### Manuscript Info

##### Manuscript History

Received: 17 September 2023

Final Accepted: 24 October 2023

Published: November 2023

##### Key words:-

Informal Learning, Agent-Based System, Mobile Ad Hoc Networks, Context Aware Learning

#### Abstract

Informal interaction among users may reveal significant information regarding their behaviors in small communities. Although apps like WhatsApp are very popular for informal interaction activities, they, however, lack in providing the user with contextual information of other users present in the surroundings who might be helpful in addressing the queries thus enabling focused information exchange. Thus, there is a requirement of informal interactive environments that can be built on-the-fly, providing anytime-anywhere cost-effective interaction possibilities to the users. Mobile adhoc networks that can be built over wireless networks using wi-fi enabled smart phones, can provide a promising solution to the above problem, even in regions lacking adequate infrastructure. This paper proposes MAKSS, a mobile agent-based knowledge sharing system, comprising mobile user agents to facilitate information exchange among groups of users available in a close vicinity like a college campus. In this system, a user agent belongs to two views- a) a physical view formed by cellular frequency ranges of mobile devices; b) a context view constituting a group of user agents having similar interests or contexts. These views help in dissemination of user queries and responses within a group (multicasting) or their routing to the intended persons (of same context as sender but belonging to different physical views). The simulated experiment highlights that the proposed system would work well in introducing users to the focused groups and also evaluates how user agents behave in the collaborative process of knowledge exchange on the parameters of inquisitiveness, responsiveness, reciprocity and cooperativeness.

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#### Introduction:-

In a traditional learning environment, a learner is aware of the presence of other similar learners in the local vicinity such as classrooms, but is oblivious to those present in other farther locations. This is a limitation to the norm of e-learning that advocates for providing flexible and seamless collaborative learning environment to the learners. Due to recent unprecedented covid pandemic situation, movement from traditional learning to technology-enhanced

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learning has become a necessity and a norm rather than exception. However, in technology-enhanced learning systems, the focus is on content instead of requirements of a learner. Various studies have pointed out that the inclusion of technology and media in e-learning transforms learning into a mechanized process causing a rise in disinterest among the learners (Sakkir et al., 2021). Thus, new learner-centered frameworks are needed that allow active participation and purposeful interaction of learners in knowledge creation within communities, organizations, territories and society, at large. For efficient collaboration, there must exist a community of people coexisting in space (physical or virtual), sharing a common objective, having knowledge about the objective, willing to invest time to focus on the objective and able to interact in a common language. Such communities come out with competent solutions to complex problems more efficiently than their individual members. A contextually aware system e-learning system takes context as input and evaluates user interactions in a non-deliberate process to deduce potential knowledge gaps between the tacit knowledge of the learners.

The evolution of wireless technology has been instrumental in preserving the existence of communities by providing mobility to the members and ubiquity to the online environment. Wireless technology is a boon to online users, especially online learners. It empowers learners and instructors to bring education out of classroom bounds. Using the mobile devices, learners can freely move, learn and communicate over a wireless network such as mobile ad hoc network (MANet) especially in regions where there are no adequate infrastructural facilities (Visalatchi, 2019, Ichaba, Musau and Mwendia, 2020). MANet is a self-organized, short-lived, infrastructure-less (no dependency on antennas, towers and electricity) and easily deployable network, where each node is capable of communicating with other nodes directly or indirectly through intermediate nodes. The path-sensing and mobile routing functionalities of the nodes bring out the self-organizing and self-configuring structure of the entire network. MANets have paved the path for anywhere, anytime resource accessibility to the users in a closed environment. These characteristics put in place the candidature of MANets for developing mobile learning systems where anytime accessibility to human expertise is a boon for the learners who despite being connected to the web-based knowledge banks are on their own to comprehend the information available to them. The 'anytime anywhere' ubiquity lent by MANets is quite beneficial in achieving collaboration among the students and the teachers (Bernal, Cortés, and Leguizamón, 2017).

The smart phone apps like WhatsApp or Telegram have paved way for a fast communication like chat in one to one or conferencing mode. However, there is a limitation that the app users can communicate only with the persons whose contact numbers are stored in their contact list. Also, these applications are generic in nature, that is, they do not provide a recommendation to the user regarding whom to connect to in case of a specialized query. The onus lies on the users to sense, evaluate and rely on the expertise of their contacts. These apps do not provide the user with the context information of other users present in the surrounding environment that may be useful for establishing focused information exchange.

This issue led the authors of this paper to conceive and propose a mobile agent-based knowledge sharing system (MAKSS). MAKSS allows the users to communicate through querying or exchanging messages. MAKSS is conceived as an informal knowledge sharing system comprising smart wi-fi enabled mobile devices carried by on-campus people (teachers and students). The devices act as nodes of the network. Each node represents an agent and the system is populated with two types of agents—the learner agents and the expert agents. The terms 'user' referred to in the text encompasses both learners and experts and the term 'agent' encompasses the learner-agents, the expert-agents as well as their devices.

MAKSS is based on the concept of dynamic context views. In MAKSS, a context view (CV) is taken as a set of agents with similar interests. An agent forms its context view as soon as it enters MAKSS. The agent searches for other agents with similar interests in the vicinity and adds them to its context view. Similarly, all agents form their respective local context views. The views are updated as and when an agent enters or exits the system. It is highly likely that when implemented in a real-life scenario, the users possessing similar academic interests would be able to interact in a constructive manner and solve each other's queries in a meaningful way.

The objective behind evolution of MAKSS is twofold.

1. First, MAKSS facilitates focused exchange of queries and solutions among users by utilizing the presence of those in the overlapping regions (who help in forwarding the messages). Formation of CVs makes the users aware of the presence of other users, belonging to similar contexts, available to answer their queries. This information encourages the users to engage in query-response-forward process and provides focused (context-based) information to the users leading to knowledge construction and sharing in an informal way.

2. Second, user interaction in MAKSS environment leads to behavioral classification of the users. The system classifies its users by analyzing their interaction patterns. On the basis of the actions performed by the users, they are classified as inquisitive, responsive, reciprocal and cooperative. The behavioral classification is of immense significance as the collaborative process of knowledge exchange in a MANet-based environment cannot survive without the users exhibiting the above-mentioned characteristics.

The paper presents the theoretical and technical underpinnings utilized in the development of the MAKSS framework in the forthcoming sections to enhance the reproducibility of the system. A simulated useragent-based case study is also presented to reflect the applicability of the system in a collaborative learning environment. The outline of the paper is as follows. The next section presents the state of the art in the field of MANet-based learning systems. Section 3 presents the MAKSS framework. Section 4 puts forth the case study and experiment. Section 5 discusses the results and analyses of the experiment. Section 6 concludes the paper.

### **State of the art**

The affordance provided by technology has influenced the thought process of society towards learning in a significant way. Access to information within as well as outside the bounds of traditional classroom has lessened the gap between formal and informal education. Another benefit of mobile learning is that the learners rather than playing the role of mere information receivers, actively participate in the process of knowledge construction through collaboration. ML characterizes in propagating collaborative learning among the learners. Naismith, Lonsdale, Vavoula and Sharples (2004) emphasize the fact that the potential of mobile technologies lies in embedding the usage of individual devices in the learning process inside or outside the classroom to facilitate effective learning.

To realize the proposal, many researchers have implemented e-learning systems over MANet. König-Ries and Klein (2002) use the services of MANet with a focus on information services supporting e-learning applications. Grew, Giudici and Pagani (2006) present the design of a distributed platform to support pervasive learning and interactivity on a university campus and describe the functionalities of the modules and the inter-relationships among modules constituting the platform. Kalaavathi, Madhavi, Vijayaragavan and Duraiswamy (2009) propose to establish a virtual class room (VCR) based on MANet. VCR can be established immediately where members can be added or removed dynamically and is able to support urgent and timely learning activities.

Context also plays an important role in MANet-based learning systems. A context is defined as any information that can be used to characterize the situation of an entity that can be a person, a place or an object (Dey and Abowd, 2000) and a physical or a computational object (Schilit, 1994) that is considered relevant to the interaction between a user and an application, including the user and the application themselves. In a collaborative learning environment, awareness of contextual information, like location, time, nearby people and devices, and user activity (Chen and Kotz, 2000) helps the learners to strike a balance between individual and shared activities. The context information is important for defining the interaction between users and the technology (Tapia, Abraham and Corchado, 2010, Vladiu and Constantinescu, 2011). Hwang, Yang, Tsai, and Yang (2009) present the experimental study conducted in context-aware ubiquitous environment. Their findings point that the u-learning system is much more organized than traditional instruction and provide a systematic learning facility to increase learning efficiency.

The MAKSS approach proposed in this paper finds its basis in the notion of context awareness and takes it further to classify the users based on their behavioral pattern. It also provides the services associated with the spheres, relevant context information and scenarios that could be assigned to each of the services. The formation of PVs and CVs in MAKSS realize the social and knowledge contexts of the CA model respectively. MANet environment provides the technical infrastructure to MAKSS that defines the technical context as given in the CA model. The visualization aspect as discussed in the model is supported by various data structures stored on the devices of the users to provide them with the contextual information about their peers in the MAKSS environment (discussed in the forthcoming section).

### **Mobile agent-based knowledge sharing system (MAKSS)**

A small campus, like any public place, is characterized by continuous commotion. But unlike public places, where people are largely strangers to each other, the groups in the campus are cohesive as most of the faces are familiar and friendly. The population comprises mostly students and teachers having an underlying intent to exchange purposeful information and acquire knowledge in turn. These individuals move, assemble, converse and collaborate with each other leading to evolution of assorted groups and finally part away causing the group structures to wither

away. The process of group formation is thus highly dynamic and ad hoc in nature. Looking at the resemblance of the group dynamics in a closed campus environment to the characteristics of a MANet, it was thought appropriate to develop a knowledge sharing environment using MANet.

### MAKSS overview

MAKSS, the proposed system, facilitates synchronous and asynchronous modes of information exchange among on-campus groups of users. The system is designed on the basis of the following assumptions:

1. A user becomes a part of the MAKSS environment through a personalized agent as soon as she/he enters the university campus.
2. It is assumed that all on-campus users have portable devices capable of communicating with each other.
3. The campus is divided into multiple and overlapping radio frequency ranges.
4. A wireless handheld mobile device may be tuned to two overlapped radio frequencies simultaneously.

Assumption (1) and (2) are necessary to build the premise of exchanging information over mobile devices. Each device has a unique identification number- a MAC address or an IP address. On the basis of assumptions (3) and (4), MAKSS makes use of the multiple and overlapped frequency ranges to form physical overlapping views. It further groups the learner and expert agents with similar academic interests into context views. This is done by extracting the relevant context information from the profile of the device-owner stored in the device. Thus, a user agent belongs to two views- (a) a physical view (PV) formed by cellular frequency ranges; (b) a context view (CV) constituting user agents having similar interests or contexts. Henceforth, the user agents belonging to a particular CV would be referred to as 'in-CV' and the rest would be referred to as 'out-CV'. The PV (neighbourhood) information of all the agents is stored in the Physical View List (PVL). Each device has its own PVL that gets updated in the event of any change in network topology leading to change in PV (an event triggered due to a user agent joining in or leaving the current frequency range). CV information of the user agent consisting of the knowledge context (topic of interest) gets stored in the Context View List (CVL) as explained in later section. The agents generate CV\_IDs from the context information stored in their personal profiles. Both the views help in dissemination of user messages (queries and responses) within a group (multicasting) or their routing to the intended persons (of same context as sender but belonging to different physical views). The query-response mechanism happens in real time in synchronous mode. The collaboration among the users builds the centralized knowledge base of the system that can be referred to by all users in asynchronous mode. Fig 1 presents the proposed MAKSS framework. As illustrated by the figure, the on-campus users with their devices constitute the MANet environment. Each mobile device is capable of communicating with neighbouring devices through its agent. MAKSS provides the users with user interface on their devices. The user has to register and log-in into MAKSS. As she/he logs-in, a representative agent is created on his/her device. Now the user becomes a member of the MAKSS environment and is provided with the facility to interact with other user members of the system and exchange information in the form of query/response messages.

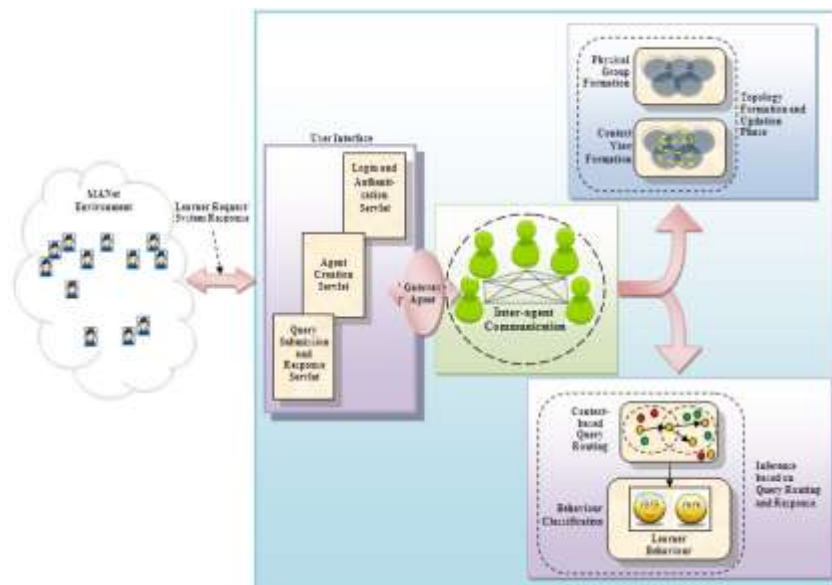


Fig 1:- Framework of (Mobile Agent-based Knowledge Sharing System (MAKSS)).

**The conceptual framework of MAKSS**

The conceptual framework of MAKSS can be articulated as follows. Let  $\mathcal{F} = \{\mathcal{F}_1, \mathcal{F}_2, \dots, \mathcal{F}_f\}$  be the set of overlapping frequency ranges in the MAKSS environment. Let  $\mathcal{N} = \{\mathbf{n}_1, \mathbf{n}_2, \dots, \mathbf{n}_m\}$  be the set of agents residing in the devices of the users present in the MAKSS environment at any instant in time and  $\mathcal{C} = \{\mathcal{C}_1, \mathcal{C}_2, \dots, \mathcal{C}_c\}$  be the set of varied academic contexts available on campus. The set  $\mathcal{N}$  is dynamic in nature as the users in the ad hoc environment are on the move and may change their positions from one PV to another or may leave the environment all together. Let  $\mathcal{PV} = \{\mathbf{PV}_{\mathcal{F}_1}, \mathbf{PV}_{\mathcal{F}_2}, \dots, \mathbf{PV}_{\mathcal{F}_f}\}$  be the set of physical views one for each frequency range and  $\mathcal{CV} = \{\mathbf{CV}_{\mathcal{C}_1}, \mathbf{CV}_{\mathcal{C}_2}, \dots, \mathbf{CV}_{\mathcal{C}_c}\}$  be the set of context views one for each academic context. If  $\mathcal{F}_x$  and  $\mathcal{F}_y$  (where,  $\mathcal{F}_x \in \mathcal{F}$  and  $\mathcal{F}_y \in \mathcal{F}$ ) be any two distinct frequency ranges;  $\mathcal{C}_i$  and  $\mathcal{C}_j$  be any two distinct academic contexts;  $n_s$  and  $n_r$  (where,  $n_s \in \mathcal{N}$ ,  $n_r \in \mathcal{N}$ ) be the sender and receiver agents and  $n_o$  (where  $n_o \in \mathcal{N}$ ) be any forwarding agent present in the overlapping region of  $\mathcal{F}_x$  and  $\mathcal{F}_y$ , then MAKSS routes the messages from  $n_s$  to  $n_r$  under the following situations:

**Situation 1:** Both the sender and the receiver belong to the same PV as well as the same CV.

**Situation 2:** Both sender and receiver belong to the same PV but different CVs.

**Situation 3:** The sender and the receiver belong to different PVs but same CV.

**Situation 4:** The sender and the receiver belong to different PVs and different CVs.

In situations 3 and 4, the sender and the receiver are present in different frequency ranges, so a mediating (or forwarding) agent must be present in the overlapping region to maintain the connectivity in the network. In case of there being more agents than one, in the overlapping region, a decision has to be made on who finally forwards the query. This decision has to be based on the number of overlapping PVs the mediating agent is part of and the total number of mediating agents in the relevant overlapping range. The number of overlapping PVs for all agents is stored in Overlapping View Table (OVT). Total number of mediating agents in the relevant overlapping ranges is stored in the Forwarding Table (FT). Each device maintains its own OVT and FT that get updated in the event of topology change leading to PV change.

**User interface**

The system provides the users with an interface on their devices for registration into MAKSS (as shown in Fig 1). The user registers herself/himself via Login and Authentication servlet. After logging-in, a representative agent of the user is created through Agent Creation servlet and she/he becomes a member of the MAKSS environment. The system provides the user with the facility to interact with other members of the system and exchange information in the form of query/response messages. The Query Submission and Response servlet facilitates the exchange of queries and responses to and from various agents in the system via gateway agent.

The user is requested to fill in the personal and academic details related to qualification, areas of interest, hobbies and so forth. This part is optional and the user may decline to provide the details. However, the information, if provided, benefits MAKSS and equips it better to handle context awareness. The pieces of information, both location-based and that provided by the user, are sensed by the agent present on the user’s device and utilized to form PVs and CVs for other members in the vicinity.

**Inter-agent communication**

The agents communicate with each-other and with the interface through the Gateway Agent in Agent Communication Language (ACL). The inter-agent communication serves the following purposes: i) PV formation and updating; ii) CV formation and updating; iii) query message transmission from a user to all MAKSS members (in-CV or out-CV both) and iv) response message transmission that involves routing solutions from the responders (all message receivers may not respond) back to that user.

**i) PV formation and updating.** Initially the agents present in the environment send introductory messages containing context ID to each-other. The receiving agents acknowledge back with their introductory messages. This process helps in PV formation thus forming a neighbourhood list of agents. The introductory messages are exchanged in the form of Introductory Message Objects (IMO). The format of a typical IMO is presented in Table 1.

**Table 1:-**Introductory Message Object (IMO) format.

|                   |                  |                  |
|-------------------|------------------|------------------|
| IntroMsg_ID       |                  |                  |
| <i>IM_ID</i>      |                  |                  |
| Agent Information |                  |                  |
| <i>n_i_ID</i>     | <i>n_i_PV_ID</i> | <i>n_i_CV_ID</i> |

|               |
|---------------|
| Intro Message |
| “Hello”       |

PV updating is required in the event of any change in network topology leading to change in PV (an event triggered due to a user joining in or leaving the current frequency range) and hence change in CV. The changes in PVs are logged into the PVLs, maintained by each agent on its respective device. PVL has four attributes namely, Node\_ID, In\_Time, Out\_Time and PV\_Instance\_No. Node\_ID stores the IP address or MAC Address of the user device that lies in the PV of the current agent. In\_Time and Out\_Time, respectively, store the times at which the user entered or left the physical group (frequency range) being talked about. PV\_Instance\_No. stores the instance number of the current PV. To ensure consistency of the network topology, all nodes must have identical physical view. Therefore, same PV\_Instance\_No should be stored at each node.

**ii) CV Formation and Updating.** The introductory messages exchanged during PV formation contain context IDs of the communicating agents. These IDs are used to form CVs within the respective PVs. In this way, all the agents add the names of other agents with similar context information to their respective CVLs. CV updating is required in the event of any change in network topology leading to change in PV. The changes in CVs are logged into the CVL, maintained by each agent on its respective device. CVL stores two attributes- Node\_ID and CV\_Instance\_No. Node\_ID stores the IP address or MAC Address of the user device that lies in the CV of the current agent. CV\_Instance\_No. stores the instance number of the current CV. It serves the similar purpose as PV\_Instance\_No, that is, to maintain contextual consistency of the network. In this case also, all nodes must have identical context view. Therefore, same CV\_Instance\_No should be stored at each node.

**iii) Query transmission.** When a user agent wishes to send a query, a query object (QO) is created. The QO embeds Query ID, Query Context, Querying Agent Information (QAI), Forwarding Agent Information (FAI), and Query Message. Query context is the broad subject area to which the query belongs. QAI and FAI are three-tuples consisting of respective agent's Agent\_ID, its PV\_ID and its CV\_ID. The Query Message is a string containing the question posed by the user to other users of the MAKSS environment. The QO is sent through the interface to the gateway agent. The gateway agent accepts and transmits the QO to all the agents present in the same PV as the query-sender.

The agents present in the overlapping regions of two or more PVs play an important role at this juncture. These agents act as forwarding agents (FA) that help in propagating the query messages in the entire network. Every agent maintains two lists for storing forwarding information- i) a Forwarding List (FL) and ii) an Overlapping Physical View List (OPVL). FL consists of FAs and the information about their respective PVs that overlap with its own PV.

FL is a list containing the set of FAs lying in the PV of the current agent. It has four attributes namely, Node\_ID, PV\_ID, In\_CV\_Fwd\_Count and Out\_CV\_Fwd\_Count. Node\_ID stores the IP address or MAC Address of the user device that lies in the PV of the current agent as well as in other overlapping PVs. PV\_ID is the ID of the overlapping PV. In\_CV\_Fwd\_Count and Out\_CV\_Fwd\_Count store the number of in-CV and out-CV queries forwarded by the respective agent. These two attributes are used in user behaviour analysis as discussed in section 4.6. OPVL is a list containing PV\_IDs of all the PVs of which the current agent is part of (as shown in Table 7).

The information stored in OPVL is used for forwarding the messages from one PV to other PVs via FAs. If an agent's OPVL has more than one entry, it is an FA and is capable of forwarding the QO to agents in other overlapping PVs. Upon receiving the QO, FA scans its OPVL to obtain the set of PVs (other than the one from which it received the QO) and forwards the QO to the constituting agents. While forwarding QO, every FA appends its unique ID, PV\_ID and CV\_ID to the query message in QO.

**iv) Response Transmission.** If a user agent (receiver) wishes to respond, the agent extracts the query information from the QO and replies the solution back to the QA. If the user is reluctant or busy, the QO is discarded by the agent. The agent of the responding user forms a response object (RO) by embedding the solution into the RO message. RO is routed back to the QA on the same path as followed by QO but in the reverse direction.

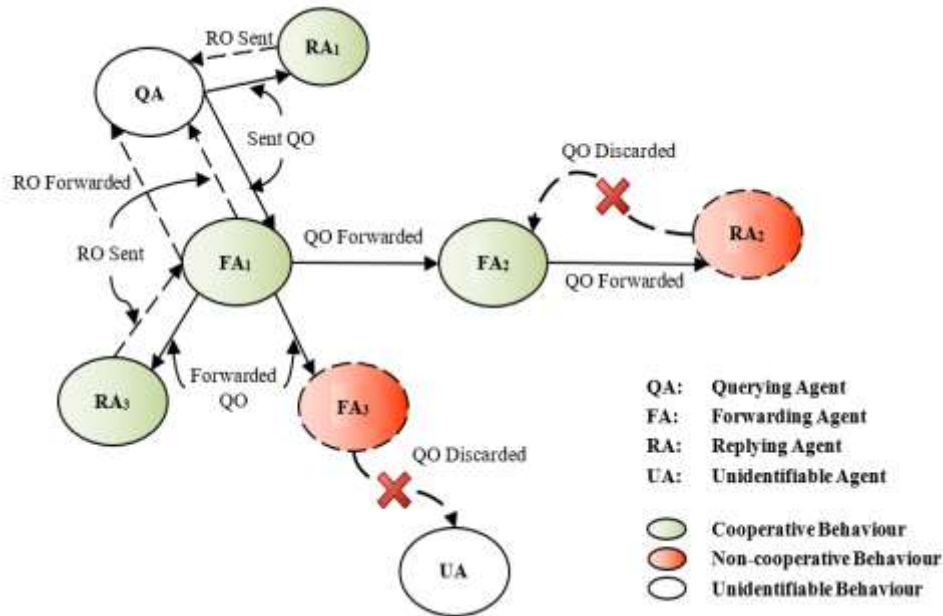
#### **Agent action-behaviour relationship**

MAKSS finds its strength on the cooperativeness of the users through their agents. The actions of agents are defined according to the device-settings customized by the users. For example, if a user wishes to participate in forwarding/replying or discarding the query, she/he sets the device in respective modes so as to allow the agent to perform the corresponding actions. The actions performed by agents during message (query/response) routing define their social behaviour over a period of time. If an agent (lying in the overlapping region) cooperates in forwarding

the query message to other agents, or provides a solution to an in-context query, it is perceived as a cooperative agent, otherwise a selfish one. It is to be noted, however, that if an agent fails to cooperate once a while due to unavoidable conditions, it should not be adjudged as selfish. The actions of agents are observed over a period of time to conclude about their behaviour. If an agent persists to be non-cooperative within that interval, it is marked as selfish.

Fig 2 presents the action-behaviour scenario of agents present in MAKSS. The agents are capable of performing the following actions: Send QO, Forward QO, Discard QO, Send RO and Forward RO.

Fig 2:- Agent action-behaviour diagram.



Based on these actions, the agents are classified as QA, the querying agent, RA, the replying agent, FA, the forwarding agent and UA, the unidentifiable agent. The query actions (Send QO and Forward QO) are shown using solid arrows. The response actions (Send RO and Forward RO) are shown using dashed arrows. Discard QO action is shown using dashed arrow with a cross. Non-cooperating agents are highlighted using red color and co-operating ones are shown in green color. The agents that could not be reached due to non-cooperative behaviour of other agents cannot be classified as either cooperative or non-cooperative. These agents are unidentifiable agents.

QA broadcasts the query (QO) to the two agents present in its range, namely RA<sub>1</sub> and FA<sub>1</sub>. RA<sub>1</sub> cooperates and sends the reply (RO) back to QA. FA<sub>1</sub> exhibits the cooperative behaviour by replying its own solution to QA, forwarding the QO to RA<sub>3</sub>, FA<sub>2</sub> and FA<sub>3</sub>. RA<sub>3</sub> cooperates by replying back, but in this case, the RO is routed back to QA via FA<sub>1</sub>, again showing the cooperating behaviour of FA<sub>1</sub>. FA<sub>2</sub> is shown to have forwarded the QO to RA<sub>2</sub>, but not replied back. Further, there is no reply from RA<sub>2</sub> also. The scenario also shows that the behaviour of UA cannot be established due to non-cooperation of FA<sub>3</sub>.

As discussed above, the agents work in accordance to the customizations done by the respective user and impersonate her/his personality. Thus, the action-behaviour analysis of agents eventually reflects the social behaviour of the users leading to their behavioral classification. The following section presents an example scenario of MAKSS and simulates its features for a clear understanding of the system.

### Simulated case study

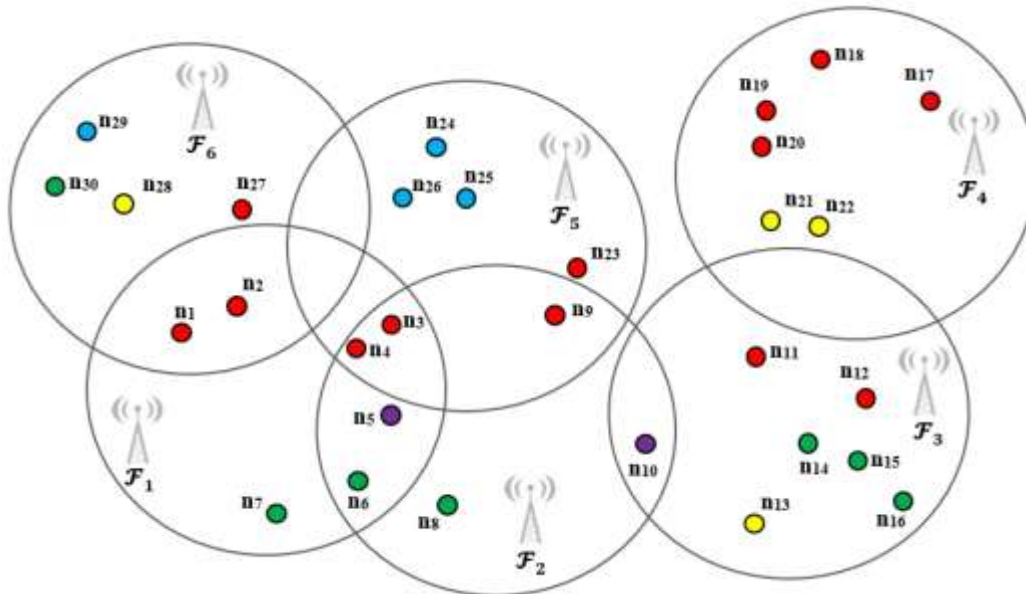
A simulated study was conducted to validate MAKSS, the proposed system. Since the system was conceptualized as a knowledge sharing environment for users in an academic setting, it was decided that software agents would be programmed to simulate users belonging to an academic institution. The authors brainstormed and populated the database of various agents with questions and answers from five subject domains. It evolved from the discussions that the subjects be chosen from inter-related disciplines to facilitate responsiveness and knowledge sharing among

participants. The questions and answers were chosen from the disciplines of computer science, mathematics, statistics, operation research and commerce were earmarked for the study. Five groups were created with a random mix of questions from all subjects, viz.-Group 1; Group 2; Group 3; Group 4; and Group 5. The CV of an agent would eventually be decided once the agent interacted with queries and responses pertaining to a particular subject (context) more than other subjects (contexts).

**Simulation environment**

A prototype of MAKSS was simulated in Java-based JADE (Java Agent Development Environment) and Netbeans, the Integrated Development Environment (IDE) for programming. The centralized database was implemented in MySQL which stored the queries and responses exchanged among the user agents during the study. An agent MAKSS\_USER on its activation (initialization phase), invokes its setup behaviours to form its physical and context views. In the event of topology change (update phase), the agent exhibits its update behaviours to update its physical and context views. In the event of query submission by a user agent (Query and Response Transmission Phase), MAKSS\_USER invokes its routing behaviour, On the basis of the conditions met in the algorithm, the agent exhibits either (or all) of the three behaviours, namely, QA, FA and RA. Fig 3 presents the simulated environment where 30 users were represented by a set of agents  $\{n_1, n_2, \dots, n_{30}\}$ , spread across six overlapping frequency ranges namely,  $\mathcal{F}_1, \mathcal{F}_2, \mathcal{F}_3, \mathcal{F}_4, \mathcal{F}_5$  and  $\mathcal{F}_6$  (shown as circular areas).

**Fig 3:-** An instance of a MAKSS setting illustrating various physical and contextual views.



These frequency ranges formed the PVs in the MAKSS setting. The areas bounded by dashed lines represent the CVs. The figure illustrates five such views, namely,  $CV_1, CV_2, CV_3, CV_4$  and  $CV_5$  (represented by five different colours). Table 2 presents the frequency ranges, the corresponding physical views along with their constituting agents.

**Table 2:-**Frequencies, PVs and member agents in the simulation.

| Frequency       | Physical view        | Member agents  |
|-----------------|----------------------|--|
| $\mathcal{F}_1$ | $PV_{\mathcal{F}_1}$ | $n_1, n_2, n_3, n_4, n_5, n_6, n_7$                      |
| $\mathcal{F}_2$ | $PV_{\mathcal{F}_2}$ | $n_3, n_4, n_5, n_6, n_8, n_9, n_{10}$                   |
| $\mathcal{F}_3$ | $PV_{\mathcal{F}_3}$ | $n_{10}, n_{11}, n_{12}, n_{13}, n_{14}, n_{15}, n_{16}$ |
| $\mathcal{F}_4$ | $PV_{\mathcal{F}_4}$ | $n_{17}, n_{18}, n_{19}, n_{20}, n_{21}, n_{22}$         |
| $\mathcal{F}_5$ | $PV_{\mathcal{F}_5}$ | $n_3, n_4, n_9, n_{23}, n_{24}, n_{25}, n_{26}$          |
| $\mathcal{F}_6$ | $PV_{\mathcal{F}_6}$ | $n_1, n_2, n_{27}, n_{28}, n_{29}, n_{30}$               |

As evident from the figure and the table, some agents lie in the overlapping regions of various frequencies. For instance, agents  $n_3, n_4, n_5$  and  $n_6$  lie in the overlapping region of frequencies  $\mathcal{F}_1$  and  $\mathcal{F}_2$  out of which  $n_3$  and  $n_4$  also

lie in the overlapping region of frequencies  $\mathcal{F}_1$  and  $\mathcal{F}_5$  also. Similar is the case of other agents present in the overlapping regions of other frequencies. Hence these agents are crucial in maintaining the connectivity of the system due to their candidature to act as FAs. Apart from physical grouping, the agents are grouped according to their contextual interests also. The clustering done using dashed lines is the representation of various CVs present in the environment. Table 3 presents the CVs and the member agents per view.

**Table 3:-**CVs and member agents in the simulation.

| Context view    | Member agents   |
|-----------------|---|
| $CV_1$ (Red)    | $n_1, n_2, n_3, n_4, n_9, n_{11}, n_{12}, n_{17}, n_{18}, n_{19}, n_{20}, n_{23}, n_{27}$ |
| $CV_2$ (Green)  | $n_6, n_7, n_8, n_{14}, n_{15}, n_{16}, n_{30}$   |
| $CV_3$ (Purple) | $n_5, n_{10}$   |
| $CV_4$ (Yellow) | $n_{13}, n_{21}, n_{22}, n_{28}$  |
| $CV_5$ (Blue)   | $n_{24}, n_{25}, n_{26}, n_{29}$  |

### The experiment

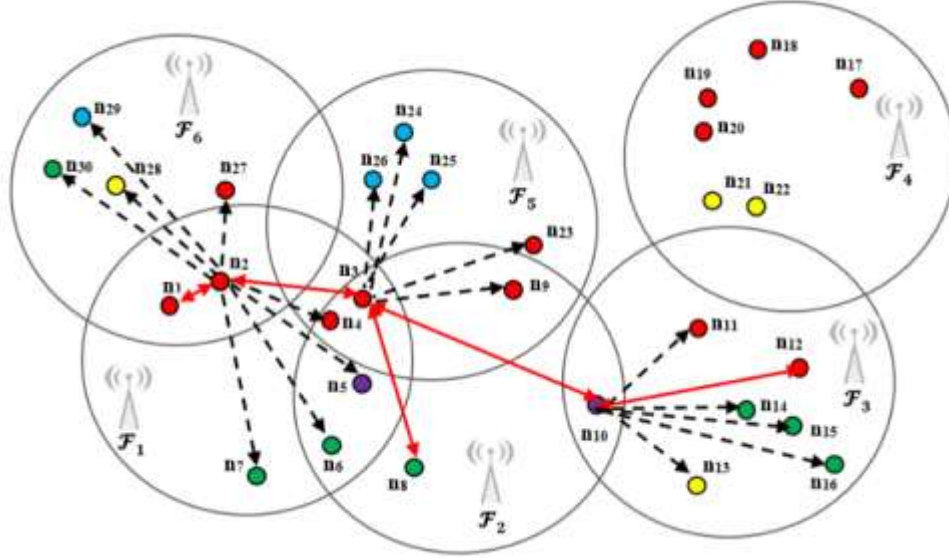
The experiment was divided into two phases. Phase I was designed to evaluate the importance of connectedness of the system. It had three sessions of one hour each where a stipulated percentage (10%, 20% and 30%) of the user agents was positioned in overlapping frequency regions. The agents were initiated raise queries belonging to mutually exclusive domains/contexts present in their respective pools of questions. Thereafter the user agents were free to ask query pertaining to any context. The data gathered from three sessions was analyzed to find out the throughput of the system in terms of total number of queries and responses generated and forwarded in each session per group.

The results from phase I established the optimal number of FAs required so that the system is connected without diminishing the performance of the system, focusing on which, phase II of the experiment was conducted. This phase allowed the user agents to pose queries and respond to queries belonging to any context (in-CV or out-CV). They were also free to forward or discard the queries and responses from any context, if they were positioned in the overlapping frequency ranges. The data gathered was analyzed to evaluate the system on the following parameters: inquisitiveness, responsiveness, reciprocity and cooperativeness, as discussed ahead in section 4.3.

Fig 4 depicts a query-response-forward event at any time instance  $t$ . The figure shows the initiation of a query by the agent  $n_2$  belonging to the physical view  $\mathcal{F}_1$  and  $\mathcal{F}_6$  and the context view  $CV_1$ . The node  $n_2$  broadcasts the query to other agents present in the physical views  $\mathcal{F}_1$  and  $\mathcal{F}_6$  (represented by dashed arrows). Out of four agents present in the overlapping regions of the frequencies  $\mathcal{F}_1$  and  $\mathcal{F}_2$ , the agents  $n_3$  and  $n_4$  belong to the same context view  $CV_1$  (as the agent  $n_2$ ) and are hence the candidates to forward the query to other agents in the physical view  $\mathcal{F}_2$ . At this juncture, it is important to notice that agents simulate human users and are programmed to react in a similar manner. In this example,  $n_3$  agrees to be the forwarder but  $n_4$  is non-cooperative (maybe reluctant or selfish). All agents in the physical view  $\mathcal{F}_2$  receive the query message but only  $n_{10}$  acts as a forwarder here as it is the only agent lying in the overlapping region of the frequencies  $\mathcal{F}_2$  and  $\mathcal{F}_3$ , even though it belongs to a different CV,  $CV_3$  (different from  $CV_1$ , the CV of  $n_2$ ). The scenario also depicts that the agents  $n_3$  and  $n_4$  fall in the frequency range  $\mathcal{F}_5$  as well. So, in this case also,  $n_3$  acts as FA to route the query message to all agents present in the frequency range  $\mathcal{F}_5$ . The agents lying in the frequency range  $\mathcal{F}_4$  are not reachable as there is no FA in the overlapping region of  $\mathcal{F}_3$  and  $\mathcal{F}_4$ .

In case of replying to the query, out of all the agents, three in-CV agents, namely  $n_1, n_3$  and  $n_{12}$  and one out-CV agent,  $n_8$  reply to the query of  $n_2$  (depicted by solid red double-headed arrows). The agent  $n_1$  belongs to the same PV as  $n_2$ , hence replies back directly, whereas the agents  $n_8$  and  $n_{12}$  lie in different PVs, so need the help of FAs to make their replies reach  $n_2$ . The reply sent by  $n_8$  is forwarded by  $n_3$  alone, whereas, the reply from  $n_{12}$  reaches  $n_2$  via two forwarders namely,  $n_{10}$  and  $n_3$ . The rest of the agents do not reply either due to lack of competence in the field to which the query belongs (out-CV) or exhibit their non-cooperation by discarding either the query or the response message (received for forwarding back to the querying agent). The actions of all the agents are observed over a period of time and their behaviours analyzed.

**Fig4:-** A typical MAKSS scenario depicting a query originated at the node  $n_2$  and sent to all nodes through multicasting at any instant  $t$ .



**Evaluation metrics**

The parameters, namely, inquisitiveness, responsiveness, reciprocity and cooperativeness were formulated to evaluate the performance of the proposed scheme. The system was evaluated by assessing the performances of the users on these parameters. The parameters are explained as follows:

inquisitiveness:  $I_k$  refers to the number of queries raised by an individual  $n_k$  against the total number of queries raised by other individuals in the system.

$$I_k = Q_{sent}^k / \sum_{i=1}^n Q_{sent}^i \quad (1)$$

responsiveness:  $R_k$  refers to the number of replies sent by an individual  $n_k$  against the total number of replies generated in the system.

$$R_k = Rep_{sent}^k / \sum_{i=1}^n Rep_{sent}^i \quad (2)$$

reciprocity:  $P_k$  refers to the ratio of number of replies sent by an individual  $n_k$  in response to the total number of queries received by her/him and the total number of replies received by her/him in response to her/his queries.

$$P_k = \frac{Rep_{sent}^k / Q_{rcvd}^k}{Rep_{rcvd}^k / Q_{sent}^k} \quad (3)$$

cooperativeness:  $C_k$  refers to the number of messages (queries and replies) forwarded by an individual  $n_k$  against the total number of messages received by her/him.

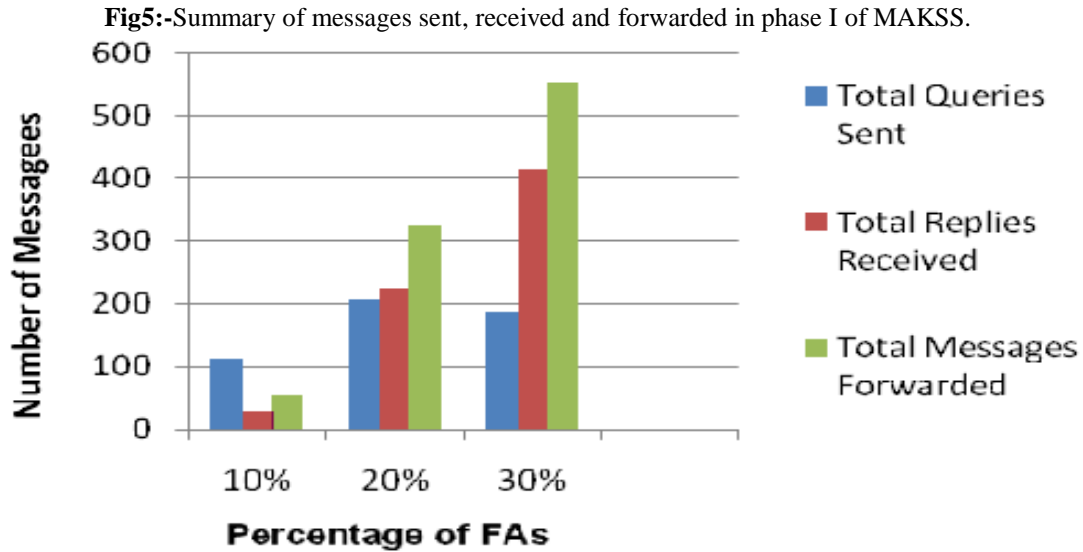
$$C_k = \frac{Q_{fwd}^k + Rep_{fwd}^k}{Q_{rcvd}^k + Rep_{rcvd}^k} \quad (4)$$

The data from the experiment was analyzed to evaluate the system along the discussed metrics and the results are presented in the next section.

**Results and Discussion:-**

The results of Phase I are illustrated in Fig 5 which shows the graphical representation of total number of queries and replies generated and forwarded in the system in three different sessions where 10%, 20% and 30% of the total participants respectively were designated the responsibility of forwarding the messages.

It is clearly seen that in the first session, the number of queries was substantial (above 100), still the number of replies received by the user agents was quite less (below 40). This is due to the fact that the number of forwarding agents in the system was only 3 (10% of the total participating agents) as compared to the total number of overlapping regions in which the participating agents were distributed. Hence some of the participating agents remained unreachable throughout the session.



The figure also shows that the number of received replies and forwarded messages were more in second and third sessions with respect to the first one. This can be attributed to the increase in the number of forwarding agents in the last two sessions.

Phase II comprised a two-day session where the user agents were free to either carry forward the discussions of Phase I or begin with new queries. The session included rounds of queries, responses and counter-queries (clarifications regarding the queries and responses). For the sake of simplicity, all types of messages were included in the data. The data was utilized to evaluate the parameters explained in the previous section. The total number of queries generated in the system was 465. The number of replies generated was 1018, however only 795 were received by the querying user agents in all. The difference in the quantities sent and received may be attributed to either non-cooperation of the FAs or non-availability of FAs in the overlapping regions. Figs 6-9 present the analysis of user (agent) behaviour measured in terms of the aforementioned parameters.

Fig 6 puts forth user inquisitiveness as calibrated on three aspects- Overall, Overall\_InContext and Individual\_InContext inquisitiveness levels. The Overall (blue) component of the graph depicts that the user agents  $n_3$  and  $n_{17}$  are highly inquisitive of the lot. They asked 29 queries each, the highest number of queries asked by any agent in MAKSS. However, there was vast difference in the number of in-context queries posed by the two. The number of in-context queries posed by  $n_3$  was also the highest in the system, that is, 29 (shown by the Overall\_InContext (red) component of the graph). Also, all the queries of  $n_3$  were in-context, whereas,  $n_{17}$  asked only 7 in-context queries out of 29 (shown by the Individual\_InContext (green) component of the graph). From here, it can be analyzed that the user  $n_3$  is more focused towards his own area of interest, whereas,  $n_{17}$  is more curious about the subjects other than his. The user  $n_{16}$  also exhibited inquisitive behaviour by posing 25 queries, though all of them were out of context queries. Further, the user agents  $n_{13}$  and  $n_{20}$  asked only two and three queries each and none of them was in-context. This may be attributed to their lack of inquisitiveness as well as disinterest in their subject.

Fig 6:- Inquisitiveness of MAKSS user agents.

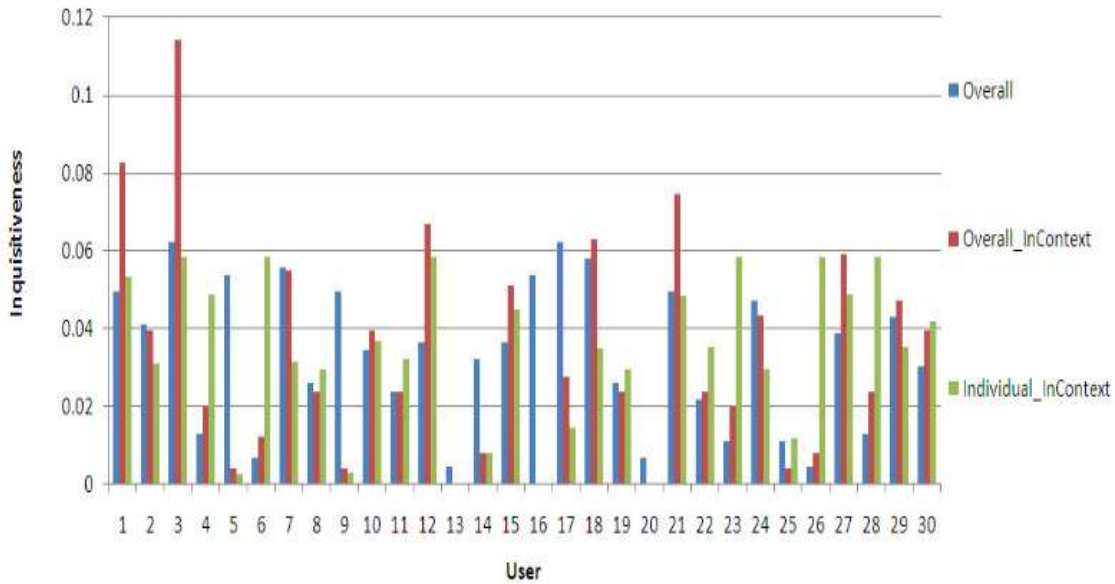


Fig 7 presents CV-wise inquisitiveness of the user agents in MAKSS. It is apparent from the Fig that the user agents belonging to CV1 (Group 1) actively participated in asking queries and hence contributed to 47.74% of the total queries generated in the system. The contribution of user agents belonging to CV2 (Group 2) was also high with 24.09%.

Fig 7:- CV-wise inquisitiveness of MAKSS user agents.

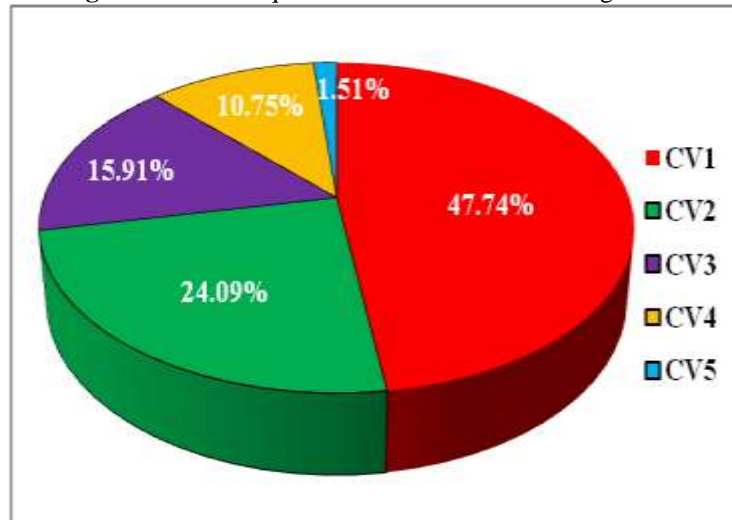


Fig 8 presents the responsiveness of the user agents along the same three aforementioned aspects. The Overall (blue) component of the graph depicts that the user agents  $n_9$ ,  $n_1$ ,  $n_5$ ,  $n_{21}$  and  $n_{30}$  are highly responsive with  $n_9$  sending a maximum of 60 responses among all. Overall\_InContext responsiveness of  $n_9$  was also the highest with 50 in-context responses. The user agents  $n_6$ ,  $n_{17}$  and  $n_{23}$  also exhibited good overall in-context responsiveness. Though  $n_1$  exhibited good overall responsiveness, yet it is evident from the graph that it sent minimum number of in-context responses, that is, three out of 59. Another user  $n_{29}$  also posted three in-context responses out of 14 posted by it in all. It seems that these user agents were more inclined towards contexts other than theirs. At individual level, 11 user agents exhibited good in-context responsiveness. The user  $n_{12}$  showed highest in-context responsiveness by posting nine in-context responses out of ten responses posted in all. Thus, it seems that the user  $n_{12}$  is more inclined towards his area of interest.

Fig 9 presents CV-wise responsiveness of the MAKSS user agents. Like in the case of inquisitiveness, here also the user agents belonging to CV1 (Group 1) actively contributed in posting maximum responses. They posted 47.35% of the total responses generated in the system. The contribution of user agents belonging to CV2 (Group 2) was also high with 22.30%.

Fig 8:- Responsiveness of MAKSS user agents.

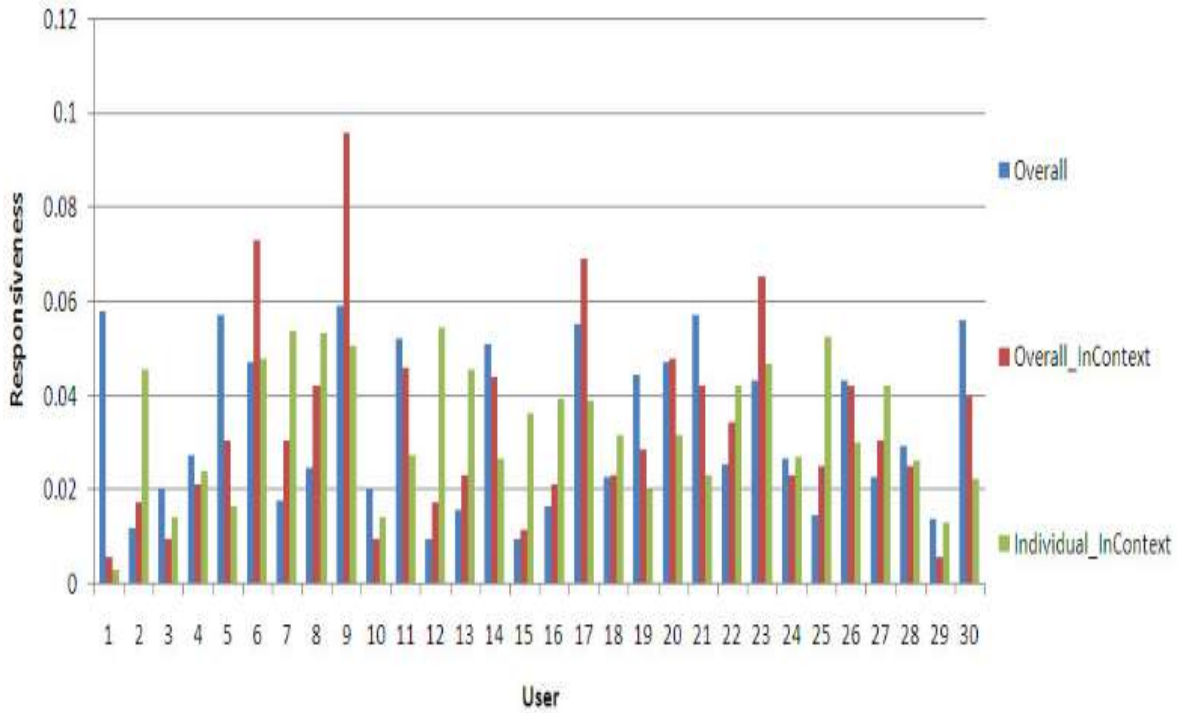


Fig 9:- CV-wise responsiveness of MAKSS user agents.

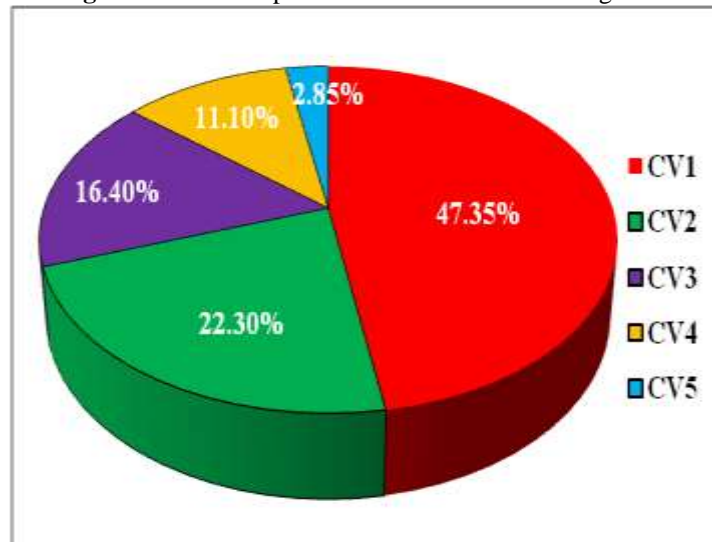


Fig 10:- Reciprocity of MAKSS user agents.

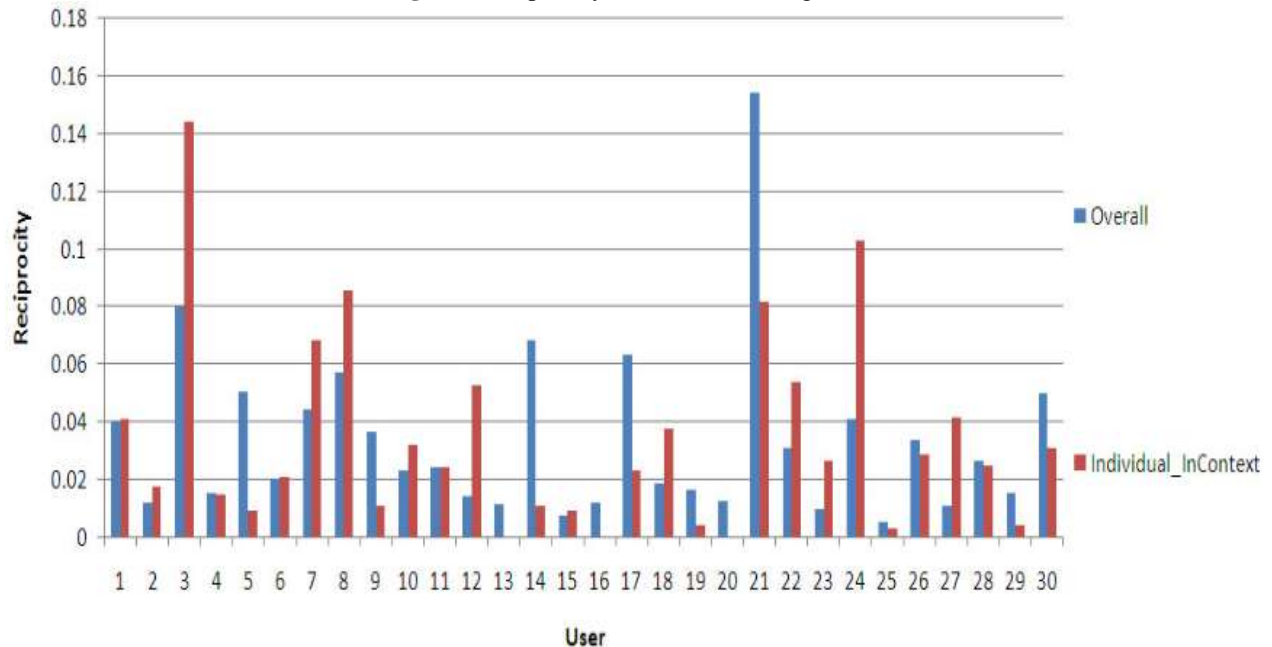


Fig 10 presents user reciprocity along two aspects- Overall and Individual\_InContext reciprocity. The Overall component of the graph depicts that the user agents  $n_3$ ,  $n_{14}$ ,  $n_{17}$  and  $n_{21}$  exhibit high reciprocity with  $n_{21}$  at the top of the list. He reciprocated more by sending a maximum of 58 responses against 21 responses received for his own queries. In terms of Individual\_InContext,  $n_3$  showed highest in-context reciprocity by posting around 50% responses to in-context queries against only 38% responses received for his own in-context queries. The user agents  $n_{13}$ ,  $n_{16}$  and  $n_{20}$  showed very little overall reciprocity and nil individual in-context reciprocity. This may be attributed to the fact that the component of in-context responses sent to queries received against that of in-context responses received to queries sent was negligible for these user agents.

Fig 11 illustrates user cooperativeness that is the ratio of total number of messages (queries and responses) forwarded with respect to those received by the user. The graph depicts that 17 of the 30 user agents (having non-zero values) acted as forwarding agents at one instance or the other throughout Phase II of the experiment. The user  $n_9$  came out as highly cooperative by forwarding all 127 (100%) messages received. User agents  $n_3$  and  $n_{22}$  followed close behind by forwarding 47 of 51 (92%) and 53 of 58 (91%) messages received respectively. On the other hand, user agents  $n_8$  and  $n_{13}$  are the least cooperative forwarders having forwarded 2 of 44 (4%) and 3 of 31 (10%) messages respectively.

Fig 12 presents CV-wise cooperativeness of the MAKSS user agents. Like previous two cases, here also the user agents belonging to CV1 (Group 1) exhibited highly cooperative behaviour as a whole and contributed to more than half (55.48%) of the total messages forwarded in the system. Similarly, user agents belonging to CV2 (Group 2) was also high with 31.04%. It is interesting to note here that the contribution of CV5 (Group 5) user agents was nil (0%). This implies that incidentally they were not positioned in any of the overlapping regions throughout the experiment.

Fig 11:- Cooperativeness of MAKSS user agents.

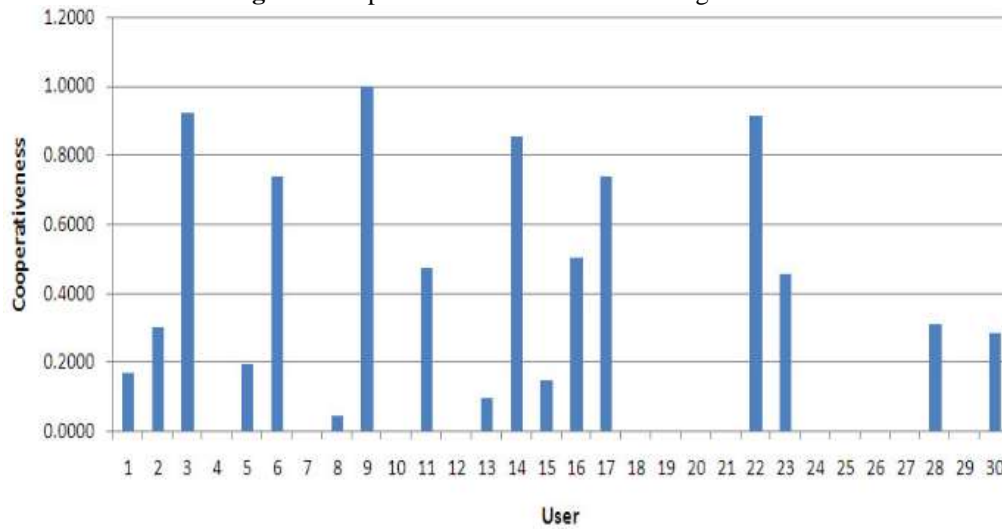
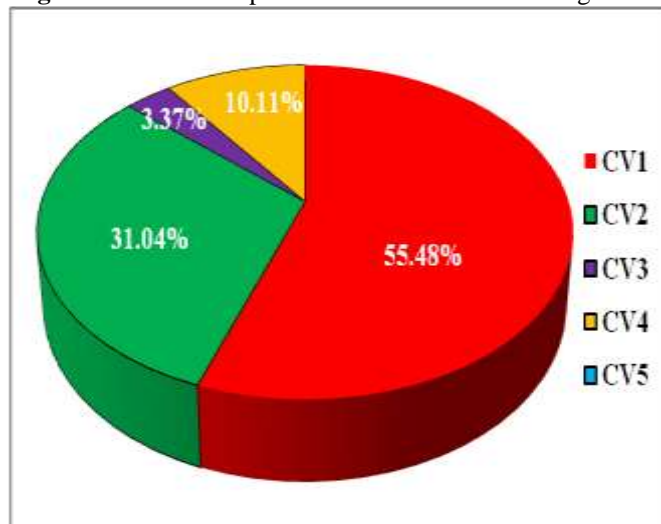


Fig 12:- CV-wise cooperativeness of MAKSS user agents.



**Conclusions:-**

This paper proposed MAKSS, a mobile agent-based knowledge sharing system, comprising agents to facilitate information exchange among on-campus groups of learners and experts. The paper discussed the design and technical aspects as well as applicability of MAKSS. The proposed approach is based on CA model that integrates knowledge, social and technical contexts of the user agents in the realms of mobile learning environment. MAKSS realized the formation of physical and context views that mapped to the social and knowledge domains of the CA model. MANet tendered the technical infrastructure to the system that defined the technical context as given in the CA model. The study points to the utility of MAKSS in interactive knowledge sharing environments. The analysis of informal interaction of MAKSS user agents proves to be beneficial in certain ways.

First, the objective of CV and PV formation within MAKSS was to facilitate focused knowledge sharing among the user agents while on the move. The user agents were continuously aware of the presence of other user agents belonging to their own context through CVs. Availability of context information helped in building a conducive environment for the user agents and let them obtain relevant, timely and assured information. PV information helped in rendering information to the user agents even in the absence of local information resources with support of user agents (forwarding agents) present in the overlapping regions.

Second, the data generated in the process of knowledge exchange paved way for behavioral classification of the user agents. The system has built in capability of classifying its user agents by analyzing their behavioral patterns. On the basis of the actions performed by the user agents during the study, they were judged on the following parameters— inquisitiveness, responsiveness, reciprocity and cooperativeness. The study brought to light how the user agents fared in the collaborative process of knowledge exchange and came out with the following observations—

1. Some individuals were highly inquisitive, some were highly responsive and yet some were cooperative.
2. High overall inquisitiveness did not imply high in-context inquisitiveness and vice-versa. The same holds for responsiveness also.
3. Some students were curious about their own subjects, as expected, however several others were more inquisitive about subjects other than theirs.
4. The CV-wise contribution of the user agents was also taken into account, analysis of which brought to light that in this particular study, the Group 1 user agents, being maximum in number, surfaced as highly inquisitive, responsive as well as cooperative. This observation, in particular, gives strength to the premise on which MAKSS is designed— the cohesiveness of the system is directly proportional to the number of individuals belonging to similar contexts.

These are interesting findings and may be analyzed further to better the real-life implementation of the PV-CV concept. Further, the analysis of query-response content generated in MAKSS could give insight into the existing knowledge levels of the users. This information may be useful in developing customized course modules in accordance to the knowledge levels and preferences of the online learners in formal e-learning environments. Though the experimental study was conducted in a simulated agent-based environment, the results provide an insight into the behavioral aspect of various users conducting themselves in a community. The experimental setup and evaluation methods used in the study are scalable for any collaborative environment. The limitations of this work, it being a simulated case study, are— a) the correctness of responses pertaining to queries posed could not be established and b) the security concerns associated with mobile agents in a real-world environment could not be addressed. These concerns along with the scalability of the proposed framework in real-world mobile network-based communities would be taken up in future studies.

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