Chapter 3

RELATED WORK

3.1 Introduction

Extensive research has already been done in the area of semantic web, ontology and agent technology. This section highlights the work of eminent researchers and explores the challenges, which still need to be addressed.

Research on agents started in 1970’s when Hewitt proposed an Actor system [26] where each Actor had an explicit internal state and had the capability to respond to the messages of other Actors. The subsequent years focused on the more theoretical aspect of bringing intelligence to software agents. In 1980’s Smith proposed the Contract Net Protocol [51], which was initially employed in a simulated distributed acoustic sensor network. It is a high level protocol which is concerned with the interpretation of the communication rather than the transmission of bit streams. CNP facilitates interaction between agents working in distributed MAS, for fully automated negotiations in the form of contracts.

Gruber (1993) in [54] described the role of ontologies in knowledge sharing activities and proposed a set of design criteria to guide the development of ontologies. Clarity, coherence, extendibility, minimal encoding bias and minimal ontological commitment [85] has been stated as set of design criteria for ontologies whose purpose is knowledge sharing and interoperation among programs based on a shared conceptualization. However the evaluation of design decisions against the criteria depends on the knowledge available and the applications anticipated for a domain. Also the ontological commitment to a strong theory is required for the sharing of valuable mathematical models.
Uschold and King (1995) in [89] identified two methods for ontology development and presented a framework for comparing and unifying them. Extension of their method and also refinement in level of granularity for different methods was left as future work.

Hagg (1996) in [121] introduced sentinels to guard functionality of agents in MAS and to protect the system from undesired states. Generalization of sentinels from mere fault handling to general abstraction level was left for future.

Song and Johns (1997) in [157] provided an overview on the basic concepts of fuzzy logic and elaborated how this technique can be applied to solve complex power system problems.

Kitamura and Mizoguchi (1998) in [154] discussed the concept of functional ontology including the functional concepts of fluid related systems only. However the evaluation and extension of ontology is not considered in this work.

Bui, Venkatesh & Kieronska (1998) in [60] presented a framework for team coordination under incomplete information based on the incomplete information games theory. When the true distribution of the uncertainty involved is not known in advance, repeated interaction among agents can help and they proved that the agents can learn to estimate this distribution and share their estimations among one another. However the integration of the proposed framework with other frameworks allowing direct communication of private knowledge of agents with other agent is left to be explored in future.

Chandrasekaran, Josephson and Benjamin (1999) in [22] provided a conceptual introduction of ontologies and their role in information systems and artificial intelligence. In their survey paper they also discussed how ontologies clarify the domain structure of knowledge and enable knowledge sharing. They emphasized gap between knowledge based problem solving and knowledge representation community and indicated that ontologies can serve as sharable knowledge resource. However they remained silent about the actual implementation of their work.

Wong and Sycara (1999) in [59] presented the design of a security infrastructure for MASs. Their framework assumes delegation of knowledge about
secrets of its employer to the agent, for proving its authenticity. However this is not advisable as nothing can prevent an agent from misusing those secrets. They emphasized on honesty of agents but remained silent about the mechanism for detecting dishonest agent.


Kumar and Cohen (2000) in [122] proposed adaptive agent architecture (AAA) and emphasized that teamwork can be used to create a robust brokered architecture that can recover a MAS from broker failure. This work provides way to find and reconnect the agents lost, in case their immediate broker fails. But the work doesn’t consider recovering the failed broker, which can severely affect the MAS depending on the importance of the broker in the system.

Till the year 2000 lot of work had been carried out in agent technology and it was emerging as a promising technology with potential scope of exploitation in various fields. In 2001 Lee et.al [128] in their visionary article laid down the foundation of Semantic Web. They gave a new direction for the information oriented WWW to be knowledge oriented in future by saying, “The semantic web will bring structure to the meaningful content of web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for the user.”

In WWW information is spread across geographically distributed, heterogeneous systems. Extraction of required information demands for an intelligent tool, capable of working autonomously and possessing mobility. Software agents being possessed with features like autonomy, learning ability, mobility, reactivity, pro-activeness and cooperation, were suitable for acting as vehicle in SW. In his vision of SW, Tim-Berner Lee (2001) very correctly visualized that agents will play major role in implementation of SW. Agent technology has proved to be instrumental in semantic web implemented so far. His article and various presentations enlightened
the powerful role of agents and ontologies in SW and gave researchers this new dimension to work on.

Maedche and Staab (2001) in [5] proposed a framework for ontology learning from legacy ontologies, from free text or from dictionaries or even from existing XML documents. However the usage semantics for imported ontologies are not clear. Refinement of methods for importing legacy ontologies is left for the future.


Martin, Sens, Briot and Guessoum (2001) in [102] proposed a framework called DARX for adaptive fault tolerance in MAS. However creation of distributed global naming service as well as design of effective replication scheme to be adopted is left for future.

Stuckenschmidt and Timm (2002) in [58] described an approach for exploiting partially shared Ontologies in multiagent communications by translating private concepts into shared ones while ensuring some formal properties. Their approach enables agents on the WWW to exchange semantic information while relying on internally provided mappings between Ontologies. However this approach still needs sophisticated communication protocols that agents can use to find out what are the ontologies shared among them and also the options for re-writing queries.

Sycara, Widoff, Klusch and Lu (2002) in [79] have defined and implemented a language called LARKS, for agent advertisement and request, and a matchmaking process using it. LARKS judiciously balance language expressivity and efficiency in matchmaking. LARKS perform both syntactic and semantic matching and, in addition allow the specification of concepts using ITL, a concept language. Its match making process uses five filters namely context matching, comparison of profiles, similarity matching, signature matching and semantic matching. Different degrees of partial matching can result from utilizing different combinations of these filters. However fielded application of matchmaking using LARKS in several application domains of agents is still an ongoing effort.
Payne, Paolucci, Singh and Sycara (2002) in [140] proposed a template based shallow parsing approach for message construction/decomposition improving the robustness of inter-agent communication but it allows exchange of simple messages only.

Mitra and Wiederhold (2002) in [104] presented various automated methods to match terms used in different ontologies however, *the methods still requires human intervention.*

The approach in [43] overcomes interoperability problem in agents on a very small database thereby, lacking scalability.

Fedoruk and Deters (2002) in [27] proposed transparent agent replication technique dealing with agent communication in replicated environment. However implementation of distributing proxy, to alleviate the single point of failure problem imposed by proxy is left as future work.

Zadeh [81],[82] emphasized that fuzzy logic plays key role in computing with words and vice-versa. His work in (2002) highlighted that Computing with words is a necessity when information available is too imprecise and also the application has a tolerance for imprecision. *Thus computing with words suits well to SW applications.*

Alibhai Z. (2003) in [158] elaborated the role of CNP in complex, truly distributed environments. He emphasized that the CNP is one of the communication frameworks which are life force of distributed systems. CNP will gain more importance in facilitating communication between agents in future. Robustness becomes major feature of the systems utilizing CNP, since small group of participating agents will be self sufficient as long as at least some of original agents survive, the system will continue to function.

Novak, Rollo, Hodik and Vlcek (2003) in [106] proposed the architecture and implementation of the security system for MASs. *However authors didn’t talk about trust among agents while communication.*

Raju and Akbani (2003) in [53] proposed a model for embedding ECC-API in existing TCP/IP model of wireless communication. However authors remained silent about detailed explanation of such API.
The algorithm [86] relies on the possibility to point to objects in the world but it failed to discuss the strategy used for pointing.

Koes, Nourbakhsh and Sycara (2004) in [23] proposed augmenting the capabilities of multi-agent systems (MAS) to provide the efficient transfer of low level information in multi-robot systems only ignoring its utility in other application areas of MASs.

Kerschhberg, Chowdhury, Damiano, Jeong, Mitchell, Si and Smith, (2004) in [80] introduces the knowledge-Sifter agent based architecture to access heterogeneous data sources. Domain Ontology is key concept in this architecture. Co-operating ontological sources are accessed by Ontology Agent. **The architecture still needs to develop tools for dynamic configuration of new sources into it.**

In order to solve complex problems, agents work collaboratively, forming Multi-Agent Systems (MAS). MAS are the backbone of SW since it is not possible to extract large amounts of precious information spread across distributed systems on the WWW without such systems in scene. MAS employ ontology for understanding the terminology of any domain. However, in order to support the variety of tasks envisaged by the current and future scenario of semantic web, different applications demands for a huge number of ontologies that must cooperate and coordinate in order to achieve the goal. With large number of ontologies on the web, mapping of ontology from one MAS to the other becomes a problem. Problem is little easier when both MAS are working in the same domain but it becomes even difficult when domains are heterogeneous. Research efforts have been made to provide mechanisms for mapping of ontologies.

As is evident from the analysis of above literature that various techniques for mapping of ontologies [27],[28],[104] have been proposed but there is no standard technique for mapping of ontologies that delegate mapping task to agents completely. Also, most of the researchers have been focusing on communication scenario of agents in homogenous domains only while very few have diverted their attention towards their application in heterogeneous domains. Therefore, an ontology mapping mechanism that is not only intelligent but also is adaptive is strongly recommended to establish standard communication methods among MAS.
Paes, Almeida, Lucena & Alencar (2004) in [24] proposed FROG to enforce secure interaction protocols in MASs. FROG allows the rules to be specified independently of the interaction language used.

Lauter K. (2004) in [76] & Xiangyu et. al (2005) in [70] elaborated the performance advantages on using ECC in the wireless environment instead of traditional cryptosystems like RSA and highlighted that security features can be more efficiently implemented in wireless devices as compared to any other technique.

Agerri & Alonso (2005) in [114] proposed rights based framework in which interaction protocols and conversation policies acquire their meaning. Rights improve interaction and facilitate social action in multi-agent domains. It mainly focuses on communication semantics and the pragmatics i.e. the rules governing the communication. Their proposal can be used to define interaction protocols using a declarative language. However extension of such interaction protocols to cover other patterns of conversations and mechanisms to punish violations is left uncovered.


Guessoum, Faci and Briot (2005) in [160] proposed architecture to augment already built MAS with a basic adaptation mechanism to dynamically and automatically update the replication strategy. However large scale real life application based validation of the proposed work is left as future work.

Khan, Sahid, Ahmad, Ali and Suguri (2005) in [161] proposed virtual agent cluster (VAC) paradigm which supports decentralized agent management systems to achieve fault tolerance in distributed agent platforms. Although development and incorporation of persistent replicated agents is left as future work.

Dimou, Batzios, Symeonidis and Mitkas(2006) in [25] developed an agent based framework called Biospider for developing and testing autonomous, intelligent & semantically focused web spiders. The framework takes the advantage of agent technology in distributing crawling load to a number of cooperating spiders.

Choi, Song and Han (2006) in [94] highlighted the need to improve methods for constructing global ontology using mapping techniques of local ontologies.

As is evident from the literature surveyed so far that ontologies are useful tool for data integration across heterogeneous data sets and play very significant role for SW. Ontology specifies a set of vocabulary for a particular problem domain emphasizing on the meaning of terms. The motive of employing ontologies in semantic web directly relates to unabated change in the languages, which are being used to describe a problem. This switch among various languages directly changes the terms used in the definition of problem assuming that the meaning conveyed will be similar to former. However the semantics might change inevitably and the purpose of upgrading a language gets defeated. Therefore the ontological databases were introduced to overcome this issue. But till now ontology building is comparatively a less absorbed concept, users are more concerned about extending already developed ontologies without getting involved in the development details of ontologies. But for optimal utilization of semantics on the web, design structure and process of ontology designing must be clear to its users. The literature was explored to outline the design issues for development of ontological database. A critical look at the literature brought up the fact that very few researchers have made an attempt to explore the dimension of ontology development; especially the evaluation of various existing frameworks is still a problem of research. Thus there is still potential for improvement in this dimension. This research has made an attempt to propose a general design structure of ontology database and also an evaluation strategy has been proposed.

Stoilos, Simou, Stamou and Kollias (2006) in [52] proposed a fuzzy extension of Ontology Web Language called Fuzzy OWL for capturing imprecise and vague
knowledge. But fuzzy OWL still needs extension on fuzzy component’s expressiveness.


Klinov and Mazlack (2006) in [109] illustrated that rough set theory can be used to complement fuzzy set theory for managing imprecision in ontologies. However their work concluded that having only certainty values as indicator of confidence in description logic axioms might not be enough for ontologies since it can not entertain vague terminology such as mostly, very, quite etc. to capture this kind of terminology linguistic variables should be incorporated in the frameworks.

Lukasiewicz (2006) in [139] presented an approach to fuzzy description logic programs under the answer set semantics. However integration of expressive fuzzy description logic into description logic program is left as future work.

As mentioned already that SW aims to provide context based information and services to the users, thus major area where it finds applicability is Search engines. Search engines provide the most convenient way of exploiting vast quantities of information spread across the web to users. Queries supplied by users may contain imprecise and uncertain information. Search engines fail to handle such queries properly, since they make use of ontologies for providing context sensitive results. Traditional ontology development methods employ crisp logical structures only, which are unable to entertain uncertainty and imprecision associated with information. But some domains of interest have subjective and inherently vague knowledge which can’t be properly expressed using crisp knowledge representation structures. Thus exploitation of knowledge from such domains becomes difficult.

In order to accommodate uncertainty and vagueness in domain knowledge one possible solution is to incorporate ability of computation with words (i.e. fuzzy logic) in semantic web at ontology level. Fuzzy logic has already been applied in wide range of applications and this technique has returned impressive results across large variety of domains where human like reasoning and behavior is required. The works [52],[113] supported the applicability of fuzzy logic in semantic web.
Analysis of literature on ontology development along with fuzzy theory, helped in concluding that fuzzy logic could be incorporated in semantic web at ontology level and although some attempts have already been made for incorporating fuzzy logic in ontology, but yet there is no standard way of developing such ontologies. There is need for well defined method of developing ontologies integrated with fuzzy logic so as to provide better results to users.

Huynh, Jennings and Shadbolt (2006) in [33] presented a trust and reputation model called FIRE, which integrates a number of information sources to produce a comprehensive assessment of an agent’s likely performance. This model is able to quickly adapt to a changing environment while still maintaining a high level of performance. However it assumes that agent report their trust information truthfully which is not possible in open, dynamic multi-agent systems. Improvement in witness and certified rating is left as future work.

Griffiths, Chao and Younas (2006) in [96] proposed a fuzzy logic based trust model to allow agents reason with uncertain and imprecise information about trustworthiness of their communication partners. However integration of this model with existing models of reputation is left as future work.

Almeida, Aknine, Briot and Malenfant (2006) in [14] proposed method for providing dependability in MAS through replication. Their work considers the criticality of the plans of the agents by taking in account the collective and individual behaviors of the agents in application.

Vacharasintopchai, Barry, Wuwongse, Nukulchai (2007) in [137] presented an overview of technologies essential for Web Services and the Semantic Web and proposed a framework for their joint application in the field of computational mechanics. This framework identifies implementation details, but doesn’t address them, which is necessary for practical application of Semantic Web Services in scientific computing. Also the framework doesn’t address issues related to trust and security.
Mika (2007) in [111] has extended the traditional bipartite model of Ontologies with the social dimension, leading to a tripartite model of actors, concepts and instances. This work includes application of this model by showing that community based semantics emerges from it through a process of graph transformation.

Vila, Schuster and Riera (2007) in [152] explored the challenges and issues to satisfy security requirements of MASs based on JADE. However authors remained silent about privacy of agents and security of mobile agents and left it as part of future research.

Wang & Singh (2007) in [156] presented a theoretical development of trust that would work in variety of situations where evidence based trust reports are desired. Their work contributes to a mathematical understanding of trust. However extension of this work from binary to multi-valued events, which will enable large variety of interactions between humans and services, is left as part of future work.

Tamma and Payne (2008) in [148] have explored various issues related to knowledge sharing among agents, in distributed, heterogeneous environments. Their work invalidates the assumption that agent posses complete knowledge of their environment at design time, due to the dynamism and scale of the environment (i.e. web).

Zheng, Kang and Kim (2008) in [138] proposed a learnable focused crawling framework based on ontology. They used artificial neural network (ANN) which used domain specific ontology to classify web-pages. The main drawback of this method is that its performance depends upon which ontology is used. Zhai, Luan, Liang and Jiang (2008) in [163] presented fuzzy ontology and RDF to represent formally the fuzzy linguistic variables. Beydoun, Low, Mouratidis and Sellers (2008) in [45] presented a model based security approach for the development of secure MASs. However their work left questions like ownership of agents and advanced agent mobility involving dynamic routing unanswered.

Novak (2008) in [105] have thrown light on the need for a lightweight communication platform for supporting development of open heterogeneous MASs. This work highlighted that although FIPA provides a high degree of interoperability
for inter-agent communication, still FIPA complying platforms are not suitable for development of open heterogeneous MASs.

Wu J. (2008) in [69] proposed a norm-based CNP for improving the efficiency and effectiveness of the coordinating processes in a MAS. This improved version of CNP provides normal and clear coordination procedure among cooperative MASs and addresses the problems born by the traditional CNP.

Although FIPA standardized CNP provides steps and briefly sketches the interaction process, it lacks specific criterion which the managers and the contractors must obey in the coordination process. This leads to various complications in its implementation and number of extensions to the basic method appear in literature to enable efficient handling of specialized interactions. The knowledge and rules existing in the coordination processes are often overlooked in traditional CNP. Further broad announcement and acceptance of the messages causes overflow and redundancy problems leading to saturation of the capacity of related agents in MASs [69].

The literature survey highlighted that researchers have made a good attempt to employ other protocols for communication among MAS [69],[105]. The literature also highlights the fact that although many researchers have worked on establishing trust among agents in one way or the other [33],[96],[155],[156] but none has focused on trust establishment amongst the agents participating in contracts through CNP.

Trust and reputation are crucial for effective communication in open MASs as agents are owned by a variety of stakeholders and they can participate or leave a system dynamically. It may be noted that participating agents are likely to be unreliable, self-interested and possessed with incomplete knowledge. Moreover, since agents are designed to behave intelligently and work in team therefore their intentions don’t remain static and hence might change with time.

The available literature as presented above strongly recommends the need of a protocol that could establish a level of trust among interacting agents.
This research has attempted to propose and improved version of CNP, with capability of trust establishment among communicating counterparts prior to start of communication.

Gladun, Rogushina, Sanchez, Bejar and Breis (2009) in [3] have proposed a Semantic Web based multi-agent system that allow to automatically control students acquired knowledge in e-Learning frameworks. Their work utilizes Semantic Web and Multi-Agent Systems technologies to overcome the problems hampering the success of e-Learning systems.

Sanchez, Garcia, Bejar and Breis (2009) in [44] elaborated the necessity for integrating intelligent agents and semantic web and analyzed the potential benefits of this amalgamation. They proposed SEMMAS (SEMantic web services and Multi-Agent System) framework, which is an ontology based framework for seamlessly integrating intelligent agents & Semantic web services. This framework still needs to be evaluated in terms of its performance & usability in several domains of practical interest.

Juneja, Iyengar and Phoha, (2009) in [35] presented an agent based semantic match-making algorithm that exploits the concept of ontology at user end and semantically enhances the user-input without considering the domain compatibility. Also this work assumes that ontological databases already exist and didn’t consider its design details.

Shanmugalakshmi and Prabu (2009) in [115] have attempted comparison between ECC and other cryptographic algorithms and elaborated the fact that ECC is advantageous over other cryptographic techniques available.

MAS involve interactions of autonomous agents to provide desired services to their users. MAS provide new services and functionalities to the users by co-operating with other agents which makes them versatile and appealing solutions. This flexibility of providing services to users raises significant security challenges for the
agents participating in communications. Literature survey brought up the fact that researchers have made attempts to provide security for communicating MAS.

The works [33],[155],[156] along with others helped in concluding the fact that security in agent communication involves two dimensions i.e. trust and security and both of them should be focused simultaneously for complete security. Literature review highlighted that although many attempts have been made to provide security in MASs communication and establishing trust among the agents, but mostly these two dimensions are considered independently or only one of the dimension have been paid attention. Very few researchers have considered security and trust simultaneously.

Literature survey [53],[115],[70] also brought up the fact that ECC cryptosystem provides same level of security as provided by traditional encryption algorithms by using considerably small key sizes. Thus usage of ECC based cryptosystems can reduce time and space complexity of the system without compromising with the security. Though Researchers have emphasized on usage of ECC in wireless communication, but none has made any effort of using ECC for providing security in semantic cyberspace. This research work presents an ECC based security engine which amalgamates trust and security as these two dimensions are intertwined and should be considered collectively for effective security of MAS.


Multi Agent Systems (MAS) like any other software system are prone to failures such as processor failure, communication link failure, software bugs and attacks by malicious agents leading to faults in MAS. However continuous service provision regardless of any failure is the most desired feature of any MAS. Fault management
in such a system spans across fault detection, fault avoidance, fault tolerance and fault recovery [122]. Fault tolerance is an approach to increase dependability of an application or system avoiding system failures in the presence of faults [73]. Inherent modularity of MAS produces some extent of fault tolerance in itself but dynamic nature of working environment, non-deterministic nature of agents and lack of central controlling authority in MAS makes it difficult to predict and handle errors, in advance. It requires improving existing architecture of agents as well as agent platforms to make these systems more effective and fault tolerant. Thus need of a strategy for providing fault tolerance in MASs is very apparent.

Replicating system components, either in hardware or software is most widely used technique for improving fault tolerance of such systems. Replication is basically creating one or more duplicate agents in the system. Each of these duplicates is capable of performing the same task as the original agent. The aim is whenever a component fails; another component shall immediately take the charge without affecting the stability of system and also, continues to provide services to the users with an acceptable delay. However, this process increases the overall complexity of the system and incurs overhead. Literature indicates that replication can be classified [37] as Active replication and Passive replication. Active replication processes the input with the help of all replicas simultaneously. It means that state of the replica is updated dynamically where as, in passive replication, only original agent processes the input messages and its state is transmitted to all its replicas periodically, in order to maintain consistency. Though active replication provides fast recovery in case of failures but it requires more cost and system resources. Thus it is preferred for hard real time applications. Passive replication on the other hand imposes less cost and resource overhead on the system but results in delays while recovering in case of any failure [37].

Analysis of literature reveals the fact that these replication strategies are employed in different ways [14],[83] by researchers to provide robustness in MAS.

*Literature review highlights the fact that although many techniques for providing fault tolerance [160], [161] in MAS have been proposed, there is no universal consensus on any one scheme. Framework called DARX provides flexibility*

Critical analysis of literature highlighted the fact that although many techniques for providing fault tolerance in MAS have been proposed, there is no universal consensus on any one scheme. This research work proposes a fault tolerance strategy which provides dynamic replication support to the MAS by adapting to change in criticality of agents. The proposed strategy focuses on providing equilibrium in active and passive replication strategies in order to reduce system complexity and resource overhead while providing efficient fault-tolerance.

Lastly the literature is explored in order to find out the metrics meant for evaluation of agent based systems or MAS. An insight into the existing literature [25],[42],[44],[58],[79],[80],[141] & [148] reflected that there are no well defined or standard metrics in literature on which agent-based frameworks can be evaluated and also not many agent based applications are available for such evaluation and analysis. Moreover, the evaluation parameters required will be different, based on the nature of application under consideration. For instance, Juneja, Iyengar and Phoha (2009) in [35] have evaluated their works using fuzzy logic. Juneja and Sharma (2007) in [34] explored evaluation metrics for Multi-agent framework employed in cellular networks. Their work highlighted the non-functional issues like coordination, performance, scalability and security on which agent based frameworks can be evaluated. Hexmoor, Lafary and Trosen (1999) in [56] provided metrics such as autonomy, timeliness and purposefulness, robustness and fault-tolerance as general evaluation parameters for agent based frameworks. Karageorgos and Mehandjieva (2004) in [4] proposed a framework to evaluate Agent Based System (ABS) engineering methodologies against a number of criteria related to design complexity. Thus the evaluation of agent based systems requires careful selection of evaluation parameters appropriate for the application in hand. Therefore after careful investigation of the available evaluation parameters, performance, scalability, stability, trustworthiness, and security are considered as the most suitable parameters.
for evaluating our proposed Multi-Agent Framework for Semantic Web (MAFSW) which will be discussed in upcoming chapters.

3.2 Conclusions

Critical analysis of above literature highlighted that although lot of work has been done in the direction of SW, but still there is scope of improvement and research. SW still requires research efforts in following areas:

- Standard mechanism for mapping ontologies of various MAS working in homogeneous or heterogeneous domains.
- Improved communication strategy, capable of establishing trust among MAS before starting communication.
- Efficient technique for ensuring secure communication.
- Efficient strategy for providing fault-tolerance to MAS.

Next chapter will be focused on addressing these issues.