# Towards XML As A Secure Intelligent Agent Communication Language

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**Abstract**: Intelligent software agents can exchange information and knowledge in a way similar to humans by using different methods of communication. This paper shows how different agent communication languages provide varying amounts of information richness similar to different media providing various amounts of information richness for humans. Agents, by definition, may perform functions to assist humans or other agents. Thus, it is imperative to have sufficient information richness between agents, between humans, and between humans and agents. Information richness theory and media richness theory provide the theoretic foundation of this paper. In the last decade, researchers have based most agent development upon highly complex artificial intelligence, rather than on simpler information system theories. I propose that the Extensible Markup Language (XML) ensemble provides sufficient information richness as an agent communication language to be the catalyst for secure business-to-business electronic commerce (B2BEC) on the Web.

**Keywords**: Agents, intelligent agents, agent communication language (ACL), XML, security, information systems, intelligent documents

## Introduction to Intelligent Systems

Researchers from the Artificial Intelligence scholarly community had developed several major areas of research during the 1980s, one of which was Expert Systems. This body of research has evolved into Intelligent Systems during the past decade. Within the area of Intelligent Systems research, Expert Systems, Knowledge Management, Machine Learning, Neural Networks, Data Mining, and Intelligent Agents have further developed. Researchers have defined intelligent agents as consisting of very little artificial intelligence and primarily computer science (Etzioni in Wooldridge, p. 22), dynamic objects in an open environment (Jain, p. 62), and user assistants or recommendation systems (Mladenic, p. 44). Researchers have further defined intelligent agents in terms of certain desirable characteristics: 1) autonomy; 2) ability to perceive and act in their environment; and 3) ability to socially interact and communicate with other agents (Gallimore, p. 111)(Jain, p. 62) (Wooldridge, p. 21).

Autonomous agents have an agent taxonomy (Klusch, p. X) for the type of agents required for conducting B2BEC. The taxonomy of an information agent follows the autonomous agents/software agents/task-specific agents/information agents path through Klusch's hierarchical tree. The classification of information agents splits into cooperative and non-cooperative information agents. Each of these classifications has the same three sub-classes: 1) adaptive agents—personal assistants and search bots; 2) rational agents—shopping bots like Bargain Finder; and 3) mobile agents like IBM Aglets (Klusch, p. XI).

Heterogeneous mobile agents require a common agent communication language (ACL) to describe and process agents' collaboration requests. Knowledge Query Manipulation Language (KQML) is the initial result of researchers to produce such a language (Wooldridge, p. 23) (Dabke, p. 56) (Aparicio, p. 8). A second attempt produced Foundation for Intelligent Physical Agents Agent Communication Language (FIPA ACL) (Fikes, p. 74) (Labrou, p. 47) (Aparicio, p. 8). However, both of these languages use message text based on the theory of speech acts (Labrou, p. 47). Recently, a third attempt has finally produced an ACL which practitioners have embraced, Extensible Markup Language (XML) (Bradshaw, p. 57) (Wales, p. 56) (Maes, p. 86) (Glushko, p. 107). One of the reasons that practitioner's have accepted XML is that although Information Richness Theory considers face-to-face as richer in information than written text (Daft and Lengel, p. 560), businesses traditionally use documents to exchange information in order to have a record of a transaction. "Indirectly, Intelligent Agents can be thought of as Intelligent documents," (Knapik, p. 126). XML organizes data by using tags to classify data into parts created by a document type definition, which can be authored and interpreted without ambiguity by other intelligent agents or by the applications receiving the XML structured data (Feldman, p. 14). Thus, in order to get the practitioner's buy-in, the research community should produce an agent architecture based on Intelligent Documents as Intelligent Agents and XML as an Intelligent Agent Communication language.

This paper introduces Intelligent Systems and briefly traces their evolution. The first section discusses agent architectures, multiple-agent systems, and ontologies. Section 2 discusses the two primary theories that provide the basis for considering Intelligent Documents as Intelligent Agents. The third section demonstrates the structured models and intelligent architectures required for communicating electronically. Section 4 shows how different types of agent communication languages are key to intelligent telecommunication architectures and Intelligent Agent development. Finally, the paper proposes a Secure Intelligent Document infrastructure model based on multimedia/hypermedia documents communicating intelligently by using XML.

## 1. Intelligent Agent Requirements

*Agent Architectures*. Intelligent Agents cannot function efficiently in chaos. In order to provide a satisfactory operational environment for the Intelligent Agents, an agent architecture must exist. This agent architecture should use persistent agents, which involve humans and change slightly with transient agents (transient agents do not need human involvement (Baker, p. 65). Such an architecture that allows a human-to-agent interface and agents that communicate with other agents will enable the community of such agents to spread across the Web or remain in a specific community domain, if the human belongs to multiple communities simultaneously (Hattori, p. 56). This agent infrastructure can support a large-scale coordinated problem-solving activity as long as it is interoperable and secure (Bradshaw, p. 53). The community agents provide shared information, knowledge, or contents within the specific community and act as mediators for informal communications between humans (Hattori, p. 56) (Hayes, p. 127). Since interagent communication is an absolute aspect of any agent architecture, the communication aspects should be patterned after the agents themselves to make the agent system robust and maintainable (Knapik, p. 85). Using XML as an ACL is less complex than using KQML or FIPA ACL. For instance, in order to accomplish this with XML, a Web Interface Definition Language could also be part of the agent architecture, to give the user an XML interface to large array of backend applications and data sources (Wales, p. 95). In order to accomplish this with KQML or FIPA ACL, the system would require: 1) a suite of application programming interfaces handling the composition, sending, and receiving of ACL messages; 2) service infrastructure for naming, registering, and facilitating basic services; and 3) code for every reserved message type that take semantically prescribed action (Labrou, p. 50). Unfortunately, agents seldom work alone. Rather, agents usually work in multiple-agent systems, which can integrate the societies of multiple-agent systems by using component based and service-oriented agent architectures (Gustavsson, p. 47). A society of multiple-agents is like a small town with cooperating family and business units.

*Multiple-Agent Systems.* Multiple-Agent systems require a more complex infrastructure than single agents. Past research involved artificial intelligence. Multiple-agent systems research used to be called distributed artificial intelligence research (Lesser, p. 133). Service-oriented agent architectures mentioned previously, must provide a basic set of services. These services include an agent server, which allows other agents to interact. Examples include yellow pages, registration, thesaurus, interface synchronization, typing, and allowing the code to be agentized by wrapping (Arisha, p. 64). Depending upon the multiple-agent system resource allocation for each individual agent, a typical message to agents will also contain a value representing how much of the shared resource it may use. Each agent develops its semantic network as long as they are allocated sufficient resources (Jamali, p. 40). Without interagent communication and agent creation, it is cost-prohibitive to implement multi-agent software (Baker, p.67). When conflicts arise within-agent as well as between agents, communication must occur. There are two approaches to resolving conflict. One focuses on external communication, collaboration, coordinated behavior, logical deductions and decision-making among multiple-agent systems; and the second approach focuses on the internal architecture of individual agents for social interaction, collaboration, decision-making, learning, and emotions (Sloman, p. 76). Research in learning and adaption in multiple-agent systems is improving coordination and control between various types of agents (Drazansky, p. 54). Coherence theory and interagent collaboration theory provide a basis for trying to understand and designing communications and interactions among agents in a multiple-agent system (Joshi, p. 39). Multiple-agent systems integrate four levels of abstractions: system; blocks, units, and primitives" (Devedzic, p. 427). "Coherence means a systematic or logical integration of diverse elements" (Jain, p. 63). Commitment theory provides a basis for understanding the promises, intentions, and obligations the agents in a multiple-agent system have toward each other as a sphere of commitment (Jain, p. 63). Future smart communications equipment will allow software agents to exist on the power grid requiring constant coordination, collaboration, and decision-making. These agents will help society in general by constantly monitoring and adjusting the control of building environments through electrical devices of an Intelligent building or similar structures (Gustavsson, p. 41). Similarly, megacorporations can be deconsolidated into loosely connected microcorporations, which will be constantly monitored with manufacturing, financing, etc. and adjusted by multiple-agent systems (Baker, p. 67). Multiple-agent systems development also needs an architecture to provide linguistic and system level support to define the relationships of individual agents and coordination between agents (Jamali, p. 40).

*Ontologies.* Individual agents communicating with one another or multi-agent systems with server agents both require some mechanism by which to represent the information or knowledge of the domain of the agents or multiple-agents system. Documents, database schema, or object schema provide the common terms or vocabulary to make up an ontology (Fikes, p. 74). One of the key components of agent development is a shared ontology, which is defined as vocabularies for agent communication and a set of relationships that holds among those vocabulary items. An ontology is a representation of knowledge about the chosen domain (Jain, p. 67). The construction of an ontology is a complex collaborative process that crosses individual, organizational, and geographic boundaries (Fikes, p. 73). Every agent incorporates some view of the domain it applies to and other entities about which knowledge is expressed and of the relationships among the entities (Labrou, p. 46). A shared ontology is extremely important in XML trading architectures (Moses, p. 80). Everyone pushing XML emphasizes XML's ability to add content processing and one-world ontologies (Petrie, p. 4). KQML and FIPA ACL offer a very narrow and inflexible way of defining base ontologies compared to XML as an ACL (Labrou, p. 51). XML schemas provide context which refers to a group of assertions about which something can be stated (Fikes, p. 77) (Floyd, p. 44). XML style sheets (XSL) provide a shared ontology for each communiqué between Intelligent Documents as Intelligent Agents.

## 2. Intelligent Communications

The intention of this section is to discuss how Information Richness Theory and Media Richness Theory provide a basis for comparison of different Intelligent Agent Communication languages. In the human environment, in order to have intelligent communications between humans, we must assume that we have an intelligent communication language, which is understandable and translatable. The natural languages form the modern basis for verbally communicating between participants of the conversation. Fortunately, the modern natural languages appear in different media such as the written form, Braille for non-visual form, signing with hands and mouth (lip-reading) for non-auditory form. The development of different media for natural languages spans eons, with the most rapid development occurring in the last half of this millennium. Similarly, languages for intelligent agents should develop in a way that closely approximates the development of natural languages but orders of magnitude faster (Labrou, p. 45). Researchers developed Intelligent Agent Communication Languages, KQML in 1993, and FIPA ACL in 1996, based on Speech-Act Theory and the medium of written text. Thus far, KQML and FIPA ACL are not translatable between agents and not understandable to most humans communicating with the intelligent agent. A speech-act is defined as a performative, which is an utterance that succeeds simply because the speaker says or asserts, queries, or commands it (Labrou, p. 47). KQML contains seven primary performatives. FIPA ACL also uses the same set of performatives but calls the same performatives "communicative acts" (Labrou, p. 48). Researchers also are developing Intelligent Agent Communication Languages based on conversation or content (such as XML and the medium of written text) but in an intelligent document which is an intelligent agent media.

*Information Richness Theory*. "Information richness is defined as the ability of information to change understanding within a time interval. Communication transactions that can overcome different frames of reference or clarify ambiguous issues to change understanding in a timely manner are considered rich. Communications that require a long time to enable understanding or that cannot overcome different perspectives are lower in richness. In a sense, richness pertains to the learning capacity of a communication" (Daft and Lengel, p. 560). The Intelligent Agent Communication languages, KQML and FIPA ACL, in their homogeneous environment, certainly meet Daft and Lengel's definition of information richness. Both of these ACLs change understanding of information in a short time interval. Later in this paper, I will make the argument that XML also meets this definition. One of KQML's and FIPA ACL's design parameters was to overcome ambiguity, which they do by having their own ontology and set of performatives/ communicative acts. XML specification 1.0 did not contain a design to completely overcome ambiguity, but the second specification, XML Style Sheet Language

(XSL), does overcome ambiguity because it clearly defines the type definition for that communiqué (Light, p. 182). Making document type definitions optional in XML allows the use of other schema languages, if needed, in place of the document type definition, which allows for richer data typing (Tauber, p. 102) or newly developed XML Schema (Mikula, p. 81). Encapsulation of semantically rich data can be addressed by XML, which allows users to specify arbitrarily structured data types between agents and legacy applications through gateways to the legacy applications, other agents, and the human user (Wong, p. 98). Thus, KQML, FIPA ACL, and XML all provide rich intelligent agent communication.

*Media Richness Theory*. "Communication media vary in the capacity to process rich information" (Daft and Lengel, p. 560). Researchers have re-looked media richness theory, considering multimedia mediums such as video, but have failed to consider intelligent agents as a new medium. Intelligent agents should be considered as a medium for communication with agent communication languages as the determination of the richness of the media. Media richness theory argues that when team members use richer media for equivocal tasks, then team members' performance of tasks improves (Dennis and Kinney, p. 256). The Daft and Lengel media information richness scale may need further calibration. Researchers added electronic mail to the media scale earlier in this decade. However, through a hermeneutic interpretation, electronic mail in and of itself was shown to be neither very rich nor less rich as an information medium. "Richness or leanness is not an inherent property of the electronic mail medium, but an emergent property of the interaction of electronic-mail medium with its organizational context, where the interaction is described in terms of distanciation, autonomization, social construction, appropration, and enactment" (Lee, p. 143). Recently, researchers found that the differences between users of email formed a basis to suggest a model for understanding the use of "rich" and "lean" communication media (Carlson and Davis, p. 335). "In order of decreasing richness, the media classifications are (1) face-to-face, (2) telephone, (3) personal documents such as letters or memo, (4) impersonal written documents, and (5) numeric documents. The reason for richness differences include the medium's capacity for immediate feedback, the number of cues and channels utilized, personalization, and language variety" (Daft and Lengel, p. 560). Intelligent agents should be categorized as 1.5 because of the capability to include an avatar (cyberspace persona of a human) that could actually be instructed to speak using the human's voice (agent-to-human) providing immediate feedback, personalization, and language variety. However, such attempts have only been undertaken in research environments. When communications operate at several different levels (such as humor) psychological mechanisms may be involved that the intelligent agent could emulate (Sloman, p. 72). "Media of low richness are effective for processing well understood messages and standard data" (Daft and Lengel, p. 560). Also, there are many conventions for using a limited medium to convey rich information (Tauber, p. 100). Thus, considering intelligent documents as intelligent agents, XML as an intelligent agent communication language can certainly process well understood messages and standard data in a document format, which would place intelligent documents as 2.5 on the information media richness scale.

## 3. Intelligent Networks

The scope of a computer network has changed drastically since the first primitive connections between computer central processing units and a simple network hub device. Next, a network server (a computer dedicated to supporting the local area network) appeared. Then routers allowed these network servers to connect over dedicated telecommunications lines

(Internet). Bridges allowed different types of networks to interface (for example, IBM network to a DEC network). Modems allowed point-to-point connectivity until modem banks and Internet service providers allowed point-to-Internet connectivity, which allowed users global connectivity. Cable-modems further expanded Internet connectivity to any place a cable-TV connection exists with a high- speed connection. Wireless modems allowed connectivity without a physical hardwire connection. Cell phones now allow a laptop or palmtop computer to connect to the Internet. Satellites can even be used to provide communication from any point on the globe with the completion of the Iridium Project. Next, local operations networks connected to the power grid may merge with data networks, to allow a computer to connect to a network through any common household electrical outlet. At the same time as the physical world barrier has become irrelevant, the amount of information and knowledge transmitted over the communications infrastructure (regardless of media type) has exponentially grown in volume. The software key to making all this happen is the intelligent agent. Some agents already wander the globe managing telecommunications for global enterprises. Unfortunately, the telecommunications conceptual architecture, once considered revolutionary in the 1980s, needs intelligent agents.

*OSI Model*. The International Standards Organization developed telecommunications standards that telecommunication corporations could develop to and allow them to sell the telecommunications products. Prior to the 1980s, telecommunications network protocols were proprietary according to the hardware manufacturer. The International Standards Organization developed an Open System Interconnect Model to which all manufacturers were to design hardware and software specifications. The Open System Interconnect Model contained seven layers.

| | | |
|---|---|---|
| Application | ^ Application ^ | Application |
| Presentation | ^ SMTP ^ | Presentation |
| Session | ^ SNMP ^ | Session |
| Transport | ←----------TCP-----------→ | Transport |
| Network | ←-----------IP X.25------→ | Network |
| Link Control | ←-----------802.3---------→ | Link Control |
| Physical | ←-----------Serial---------→ | Physical |

Network A Network B

Table 1. ISO OSI Model

The lowest layer, physical, describes the electrical standard used for making the physical connection, which used to always be some type of cable and connector with pins, for example, a 25 pin serial connector. The next higher layer, link control, describes the local area network protocol used by the network topology, for example, IEEE 802.3, a commonly used Ethernet local area network protocol. The third layer, called Network layer, normally describes the packet or frame size of the data gram sent between Network A to Network B, X.25 packet. The fourth layer, called the Transport layer, describes the transport protocol used to send between routers on the networks. The fifth layer, session layer, manages the network by controlling messages, Simple Network Management Protocol (SNMP). The sixth layer, presentation layer, directs the destination and formats the data into software readable format, Simple Mail Transfer Protocol (SMTP). The top layer, application layer, supports the graphical user interface and particular software program needed to use the application. With the explosion of networked computers, a new virtual model will be needed to support the future of telecommunications.

*The New Agent Based OSI Model.* The old seven layer model protocols will not be able to efficiently handle exponential growth of networked computers due to the sequential nature of the model. The new telecommunications model will be able to handle the exponential growth of networked computers by using parallel agent processing and intelligent interface agents. The parallel agent processing will form a virtual network consisting of intelligent agents, which can adapt to any situation, called a feedforward-feedback backplane. The seven layers will essentially consolidate to become three layers. These adaptive agents will interface to either the wired or wireless communications mode for the new bottom layer, which replaces the physical and link layers. The interface agents for the new middle layer will use a secure IP or mobile IP to transport and control the size of the packets, which will become extremely large compared to current packet sizes. The interface agents to the new top layer, multimedia, will consolidate the session, presentation, and application layers (Chorafas, p. 123).

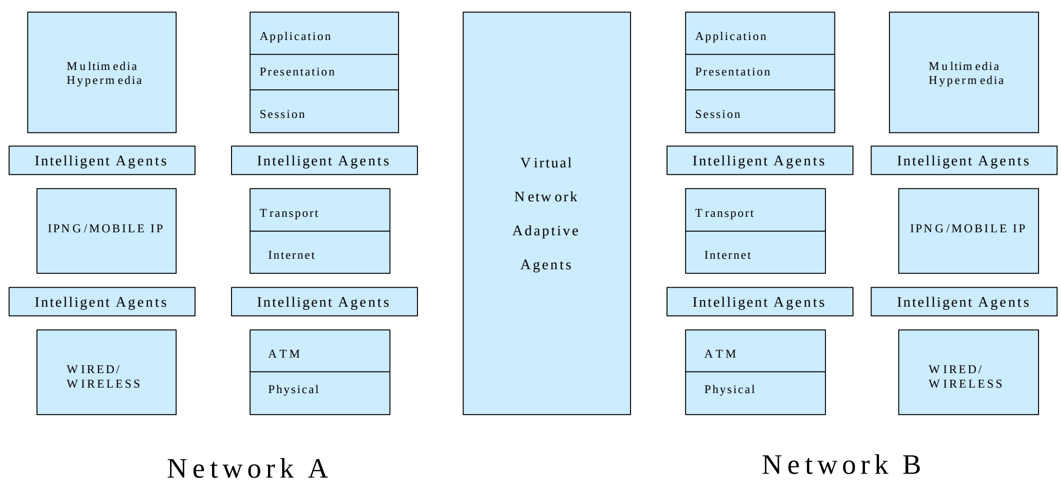


Figure 1. OSI Intelligent Telecommunications Architecture (based on Chorafas, P. 123)

## 4. Secure Intelligent Agents Communication

To this point, this paper has shown how intelligent communications require intelligent agents and how intelligent networks require intelligent agents, which will be key to future intelligent systems. This section will examine the communication aspect of intelligent agents in detail and intelligent agent communication languages in particular. As noted in the first section, autonomy is a key characteristic for an intelligent system and the most obvious autonomy preserving interaction is communication (Jain, p. 68). For example, first generation agent-mediated electronic commerce systems reduce transaction costs primarily in user-agent scenarios in the travel, theater, surplus inventory, and commodities industries. These agents operate through autonomous actions on behalf of the user without constant human intervention (Krovi, p. 18) (Moses, p. 80). Richer communication among agents will reduce ambiguous content, goals, changing environments and disconnected parties. Mobile agents are well suited for electronic commerce because different agents will have different goals and use different strategies to reach those goals (Lange, p. 89). Richer information communicated between business agents will create throwaway partnerships that exist only as long as necessary. This will allow electronic marketplaces to approach perfect efficiency (Maes, p. 91). The motto for mobile agent-based processing is simple: Move the computation to the data rather than the data to the computation (Wong, p. 92) (Lange, p. 88). What intelligent agent communication language will mobile agents in electronic commerce use?

*Intelligent Agent Communication Languages*. This paper has only discussed two primary agent communication languages (KQML and FIPA ACL) and a proposed third agent communication language (XML). Other agent communication languages exist. Scripting languages like Telescript allow straightforward addition of a new language and transport mechanisms while Agent Tool command language (Tcl) provides transparent communication among agents (Jamali, p. 41). Content languages like KQML are a deep problem-solving knowledge level because the ontologies are deep (Hendler, p. 35). XML hides the details of its internal workings while interacting, which allows it to solve problems no single agent could (Labrou, p. 45). XML also has parsers for incoming messages, which compose messages for transport and channels them through the network using lower level protocols (Floyd, p. 44) (Labrou, p. 49). Researchers have used agent communication languages to refer to four different key components in KQML and FIPA ACL—the performative, service, content and control levels (Hendler, p. 34). An example of a service is matchmaking, which is a subset of knowledge interchange format (KIF). The computer science researchers continue to endorse the Common Object Request Broker Architecture (CORBA) even though agent communication languages handle propositions, rules and actions instead of simple objects with no semantics associated with them (Labrou, p. 46). However, commercial developers are converting from CORBA-based agents to an XML foundation, due to XML's simplicity and widespread adoption by key vendors (Glushko, p. 107).

KQML is a high-level, message-oriented, text-based, communication construct language and information exchange protocol independent of content syntax and ontology (Knapik and Johnson, p. 163) (Chorafas, p. 88). Looking back at Table 1, ISO OSI Telecommunications Architecture, KQML would be independent of layer 4 and 5, the transport and session layers. KQML also would be independent of layer 6 and 7, the presentation and application layer, which would contain content directories and the actual content. In Figure 1, OSI Intelligent Telecommunications Architecture, KQML would be still be independent of the Transport layer but interface with the lower information agents in the OSI stack. Similarly, KQML would still be independent of Session, Presentation, and Application layers but interface with the upper information agents in the OSI stack. The interface with the upper information agents could occur with an Open Knowledge Base Connect (OKBC) protocol, which would allow connection to another agent communication language. The OKBC would connect to the Knowledge Interchange Format (KIF) at layer 6 and then connect to the Knowledge Base at layer 7. The KQML Intelligent Network Telecommunication stack is shown in Figure 2.

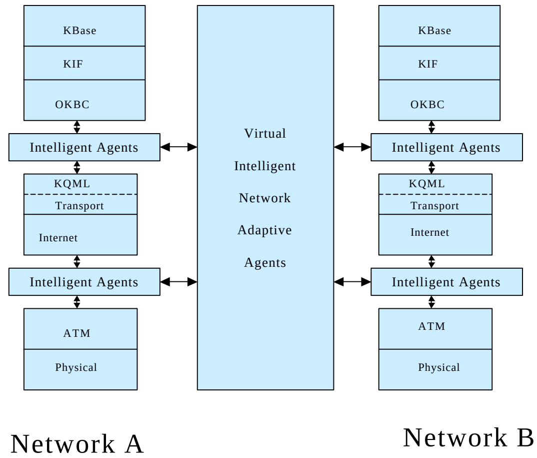


Figure 2. KQML Intelligent Network Telecommunication Stack

Researchers have noted that KQML had only an informal and partial semantic description when it was first developed ten years ago and there are still no commercial applications using KQML (Labrou, p. 48). In the research applications, KQML use has declined and the FIPA ACL is rapidly replacing KQML as the agent of researchers' choice (Jain, p.68). FIPA ACL is virtually identical to KQML except for the semantics. The two languages have the same syntax so the only way to differentiate them is to see if they are using KQML performatives or FIPA ACL communicative acts. Both languages are based on speech act theory, which is that messages are actions or communicative acts as there intent is to perform some actions by virtue of be sent as agents reflecting the attitudes of the sender and receiver (Labrou, p. 48). Agents communicate through messages or communicative acts using the context, which includes commitments to deliver resources to downstream agents or complete processes that would generate a requested product and knowledge of the completion of the action or product (Ivezic, p. 58). Both KQML and FIPA ACL use an inner and outer language to communicate. The outer language defines the intended meaning of the message and the inner language defines the content through beliefs, desires, and intentions (Labrou, p. 48).

Looking back at Table 1, ISO OSI Telecommunications Architecture, FIPA ACL would be independent of layer 4 and 5, the transport and session layers. FIPA ACL also would be independent of layer 6 and 7, the presentation and application layer, which would contain content directories and the actual content. In Figure 1, OSI Intelligent Telecommunications Architecture, FIPA ACL would be still be independent of the Transport layer but interface with the lower information agents in the OSI stack. Similarly, FIPA ACL would still be independent of Session, Presentation, and Application layers but interface with the upper information agents in the OSI stack. The interface with the upper information agents could occur with a FIPA ACL TC1 Agent Management (AM) protocol, which would allow connection to another agent communication language. The AM would connect to the FIPA ACL TC3 Agent Software Interaction protocol at layer 6 and then connect to the FIPA ACL TC4-TC7 Application Specifications at layer 7. The FIPA ACL Intelligent Network Telecommunication stack is shown in Figure 3.

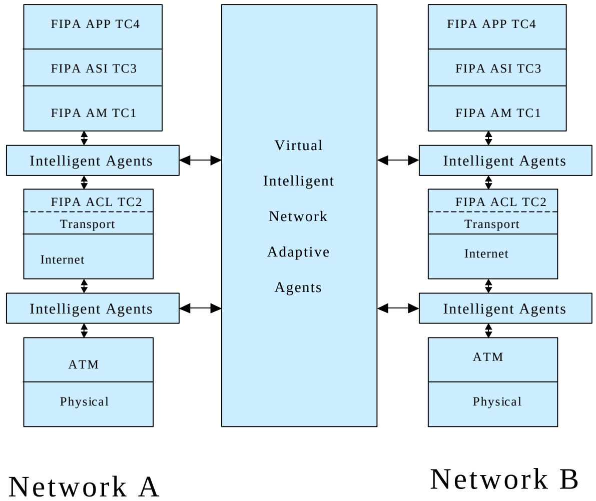


Figure 3. FIPA ACL Intelligent Network Telecommunication Stack

Unfortunately, researchers have noted there are no commercial applications using FIPA ACL and that both languages have followed a path away from the mainstream practitioners needs for Internet standards and Internet technologies (Labrou, p. 51). These researchers have generally neglected the important role of pragmatism in agent communication languages (Bradshaw, p. 57).

On the other hand, XML can make the web an agreeable environment for intelligent agents and electronic commerce (Moses, p. 80) (Glushko, p. 107). Currently, no Internet standards organization has an agent communication language in its agenda, but XML and the Resource Definition Format (RDF) seem to be strong candidates for replacing KQML even at the syntactic level (Labrou, p. 51). The major development in agent communication language syntax is that developers are increasingly abandoning Lisp-like agent communication language syntax (KQML and FIPA ACL) in favor of richly structured markup language due to the ubiquity of XML content and widespread availability of XML parsers (Bradshaw, p. 57) (Floyd, p. 44). The flexibility in markup language tag names gives XML strength to describe information in a domain or class-specific manner (Wales, p. 56). The future Internet will use XML to encode information and services with meaningful structure and semantics that computers and people can readily understand (Glushko, p. 107). Comparison shopping agents should become easier to implement and more open-minded with XML and mobile agent technology (Maes, p. 86). A large consortium of commercial vendors belong to CommerceNet, which has addressed the need for a more extensible transactional agent in support of the mobile agent structure (Wong, p. 98). EDI transactions, which currently form the basis of electronic commerce, will increasingly take place over the Internet using XML EDI (XDI) message format, which will encourage businesses to implement Web agents that communicate with XML (Glushko, p. 107).

Looking back at Table 1, ISO OSI Telecommunications Architecture, XML would depend on layers 4-7 unlike KQML and FIPA ACL which are independent of layers 4-7. In Figure 4, New ISO OSI Intelligent Network Telecommunications Architecture, XML is still dependent on the Transport layer but would interface with the lower information agents in the OSI stack.

Similarly, XML would still depend on the Session, Presentation, and Application layers but interface with the upper information agents in the OSI stack. The interface with the upper information agents could occur with an XML Data Interchange (XDI), which would allow connection to another agent using XML as an agent communication language. XDI would connect to the XML MetaData Interchange (XMI) protocol (Rhodes, p. 1) and XML Schema (Mikula, p. 81) at layer 6 and then connect to the XML Link (XLL), XML Style Sheet Language (XSL) (Ciancarini, p. 632) (Light, p. 182), XML Forms Definition Language (XFDL) at layer 7. XLL includes the specification of hypertext link types with XLink and XML Pointer. Xlink deals with how to establish links between documents or parts of documents (Light, p. 154). Xpointer deals with how to address parts of documents (Tauber, p. 100). XFDL is part of an extensible framework that integrates diverse applications over the web by putting an XML browser on a broad spectrum of applications such as stock quotes (Wales, p. 55). The Secure XML Intelligent Network Telecommunication stack is shown in Figure 4.

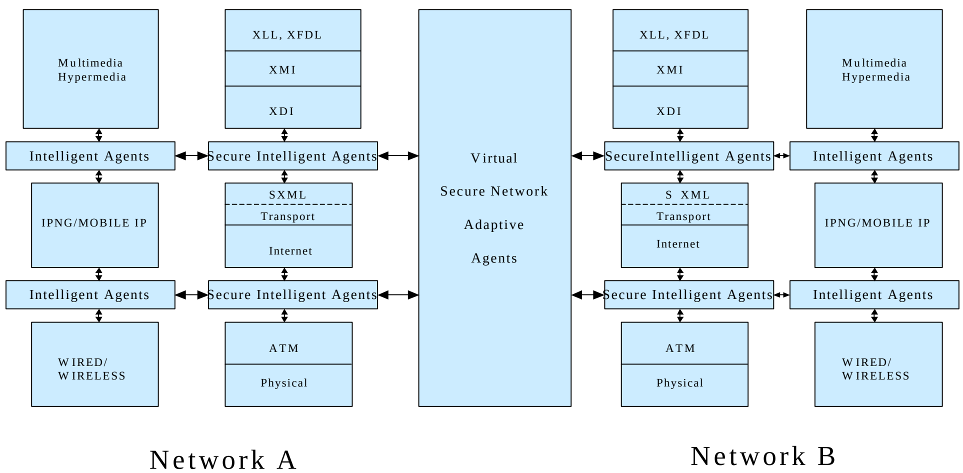


Figure 4. Secure XML Intelligent Network Telecommunications Stack

Agent development environments have largely turned to Java (North, p. 48) (Bradshaw, p. 58) (Wong, p. 95) (Wooldridge, p. 23). Along with Java, agent development environments are turning to XML (North, p. 48). Designers developed both Java and XML for the Internet. The Java development model is requiring increased and fine-grained control for agents (Bradshaw, p. 59). One example is the business components for Java tool, which organizes XML components into packages that have business objects with data properties that can be updated by changing the XML component definition (North, p. 49). However, the migration of agents depends on the agent's class definition context, which XML and Java can provide (Jamali, p. 44). The Java mobile agent development architecture consists of an agent manager, interagent communications manager, security manager, reliability manager directory manager, and and application gateway (Wong, p. 95). Specialized and standardized agents will soon appear to help build information systems as technology continues to advance (Huhns, p. 94). A key component in agent development is the agent-human interface. Currently, users are limited by current graphical user interfaces (GUI) technology, which are limiting the complexity of applications as well as the level of interaction with intelligent agents (Dyer, p. 53). Some of these limitations are from the requirement to retain legacy systems, which requires building middleware to interface with the new system (Gustavsson, p. 47).

## 5. Secure Intelligent Documents

Earlier in the paper, a statement was made that intelligent agents could be thought of as intelligent documents. With XML as the agent communication language of intelligent documents, interagent communication between intelligent documents should work securely, efficiently and effectively. Developers could model an agent as a document, composed of different XML components as shown in the previous section, and each XML component would be composed of sub-components, which could be different parts of the agent. An intelligent document would be much more than its semantic meaning of the contents. Intelligent documents could link a distributed enterprise into a secure global infrastructure of a library of super-intelligent documents as shown in Figure 5, Secure Intelligent Documents Infrastructure Model. The whole document is encapsulated in each document like from biology where the genetic map of the whole organism is found in every cell (Beer, p. 156).

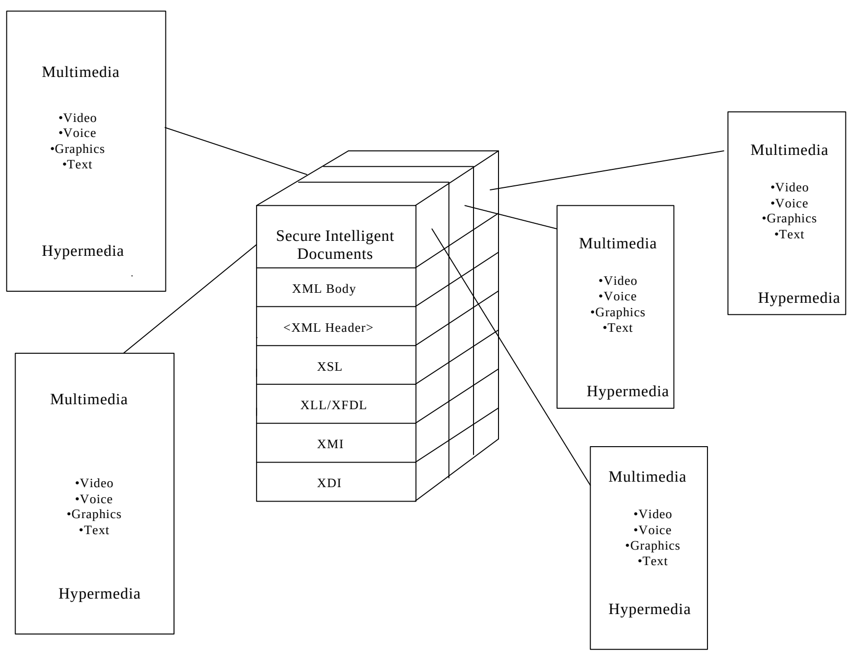


Figure 5. Secure Intelligent Documents Infrastructure Model

The Worldwide Web Consortium (W3C) has developed a platform and language neutral interface that allows programs and scripts to update the content of documents called the Document Object Model (DOM). The DOM specifies a data structure for XML documents and application program interfaces (API) for Java (Cagle, p. 56) (Floyd, p. 46). DOM grew out of earlier attempts since 1990 to standardize documents called OpenDoc, which was CORBA-based (Knapik and Johnson, p 125). DOM together with XML and Java will allow Secure Intelligent Documents to be Secure Intelligent Agents.

## Conclusions

The need for rich Secure Intelligent Communications on the Internet is by far much more pressing than other areas in typical intelligent systems. Secure Intelligent Networks will be much more capable of handling multimedia and hypermedia. Secure Intelligent Documents containing hypermedia and multimedia must have an infrastructure model to operate on the Secure Intelligent Internet. Secure Intelligent Documents as Intelligent Agents using XML may prove to be the catalyst for secure business-to-business electronic commerce.

## Need for Further Research

The Secure Intelligent Document Infrastructure Model is dependent on future research of the Internet as a Secure Intelligent Network. Secure Intelligent Documents as Intelligent Agents will require continued and extensive research particularly in the area of Secure Intelligent Communication over Secure Intelligent Networks.

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