Article

Artificial intelligence applications in the telecommunications industry

Jiayin Qi,[1] Feng Wu,[2] Ling Li[3] and Huaying Shu[1]
(1) School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing 100876, China
E-mail: ssfqjy@263.net
(2) School of Management, Xian Jiaotong University, Xian 710049, China
(3) Department of Information Technology and Decision Sciences, Old Dominion University, Norfolk, VA 23529, USA

Abstract: *Artificial intelligence (AI) has been applied to the telecommunications industry for more than a decade. The purpose of this paper is to examine the application of AI in the telecommunications industry sector. Our research finds that AI's first main application in telecommunications is in the network management area. Expert systems and machine learning are the two AI techniques that have been widely used in telecommunications, while machine learning and distributed artificial intelligence are the two AI techniques which are most promising for the future. The research also finds that different AI techniques have their unique applications in the telecommunications industry.*

Keywords: artificial intelligence, telecommunications industry, expert systems, enterprise information systems

1. Introduction

The telecommunications industry is a very specific high-tech service industry. The main feature of the telecommunications industry is its tight integration of business process and IT applications. The significance of employing IT for promoting the competitiveness of this industry sector has been well recognized (Qi *et al.*, 2006a).

The telecommunications environment is characterized by its distribution, a continuous expansion in network size, and its particular fault-tolerance requirements. These characteristics are reflected in the design of software systems. Software systems in telecommunications have to cope with a great variety of telecommunication protocols, and numerous hardware platforms and network architectures (Cselényi *et al.*, 1998). Other characteristics of such systems are their high cost, concurrency, high reliability requirements, diversity and complexity (Patel, 2002; Choi *et al.*, 2007; Ifinedo & Nahar, 2007).

Nowadays, factors such as globalization and technology innovation offer further challenges to telecommunication operations, and the industry must become more and more competitive in order to survive in a global market (A. Zhang *et al.*, 2004; S. Wang & Archer, 2007), with many more competitors and pressures for increased customer choice, lower price and improved service quality. In emerging economies, state-owned operators are fully or partially privatized in order to survive better (Stienstra *et al.*, 2004). On the other hand, a global telecommunications market provides opportunities to some large operators, such as BT and Vodafone, because of the economies of scale in telecommunication networks.

Internet technology has contributed to an extraordinary growth of Internet and IP services and applications. Customers are increasingly free to choose different service components from different vendors and assemble their own solution (F. Li & Whalley, 2004). 3G and mobile Internet accelerate the production of new services (Keryer, 2001; Pikkarainen, 2001; Meier *et al.*, 2003). Hence there has been a shift from a stable market to an increasingly user-driven market place, and the success of a telecom operator will depend entirely on the operator's ability to create services and applications that are embraced by the users.

The effective management of basic telecommunication infrastructures, a full range of software platforms, increasing varieties of services and a large customer base are very important for any operator who wants to win the market. The telecom operators must have the ability to rapidly develop, deploy and manage services to meet customers' dynamic requirements any time and anywhere.

It has been more than a decade since artificial intelligence (AI) techniques were first applied to the telecommunications industry. In 1988, as the application of AI in telecommunications began, Macleish (1988) examined the relationship between two rapidly evolving technologies: AI and telecommunications. At that time, the main use of AI in telecommunications was primarily as expert systems designed for diagnosing complex equipment in an off-line mode. In 1993, Muller *et al.* (1993) highlighted the necessity for AI in telecommunications and provided a survey of AI techniques; a brief discussion of AI in telecommunications is also given in Seshadri (1996). Since these early applications, more and more AI techniques have been applied to telecommunications. Also, during this period, both telecommunications and AI have evolved significantly; therefore a thorough review of AI applications in the telecommunications industry is now timely.

The rest of the paper is organized as follows. Section 2 describes the operation management model of telecommunications operators. A simple overview of AI techniques is provided in Section 3. The research method is introduced in Section 4. A detailed analysis of the application of AI in telecommunications is provided in Section 5. Finally, a discussion and conclusions are given in Section 6.

2. Telecommunication operation management model

Future information and communication services can be represented as three layers, as Figure 1 shows (Tada *et al.*, 2003). The infrastructure layer is at the bottom and is supported through the ubiquitous network. The services layer with pervasive computing and universal services is in the middle layer. Mobile and broadband multimedia services are positioned as the highest layer, named the application layer.

If an enterprise is considered as a system, then its operation can be considered as a process which transforms the internal resources of the enterprise into products needed by its market under certain conditions (C. Wang *et al.*, 2005; L. Xu *et al.*, 2006; Moller, 2007; Olson & Zhao, 2007; Warfield, 2007). As for telecommunications operation, the output of the enterprise is information services instead of tangible goods, while the input of the operation process is service requirement information from its customer market. According to service requirements, the telecommunications operators invest in and build networks to meet the requirements. New services are packaged into products, which are then sold to the customer market. Figure 2 describes this process.

Service flow, information flow and financial flow are the basic flows in a telecommunication operator's operation process. Customer requirement information flow begins at the customer market, and ends at the first step of the operation process. The service flow begins at the

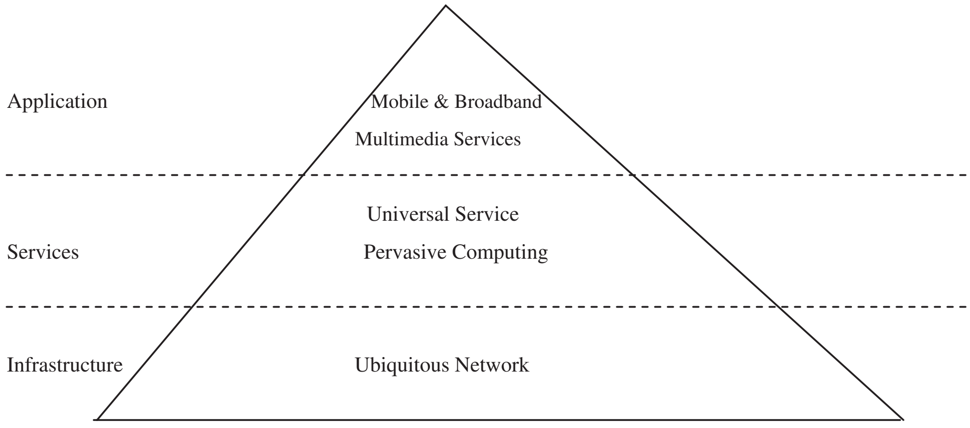

Figure 1: *Hierarchy of network services.*

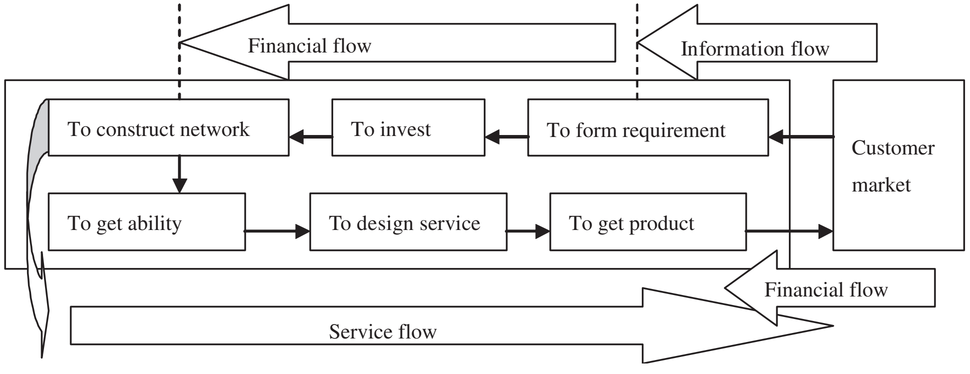

Figure 2: *The operation process of telecommunications operators.*

second step and ends at the customer market. The financial flow goes with the service flow. Obviously, the core flow is the service flow, while its efficiency is very important for enhancing the core competitiveness of the operator.

Based on the hierarchy of network services and the operation process of the operator, a telecom operator's operation management framework is as shown in Figure 3.

Customer and market management (CMM) CMM deals with the analysis of customers and markets. Based on an understanding of the changes in customers and markets, marketing, sales and customer care are provided. Prediction, decision, implementation and feedback are the four components in this module (Chen & Li, 2006; L. Li & Zhao, 2006).

Services and products management (SPM) SPM handles how services and products are offered and how to realize them. Identifying customers' potential needs on services and products is the basis for designing and developing new services and products. Rapid response to the market is the aim. As for the increasing data services, the participation of partners in the value chain is necessary (L. Xu, 2007). Services/products/partnerships life cycle management is one of the most important components (H. Li & Li, 2000).

Network management (NM) NM is about the people, procedures and tools required to effectively manage a telecommunications network at each stage in its life cycle (i.e. pre-service, in-service and future service). Network resource

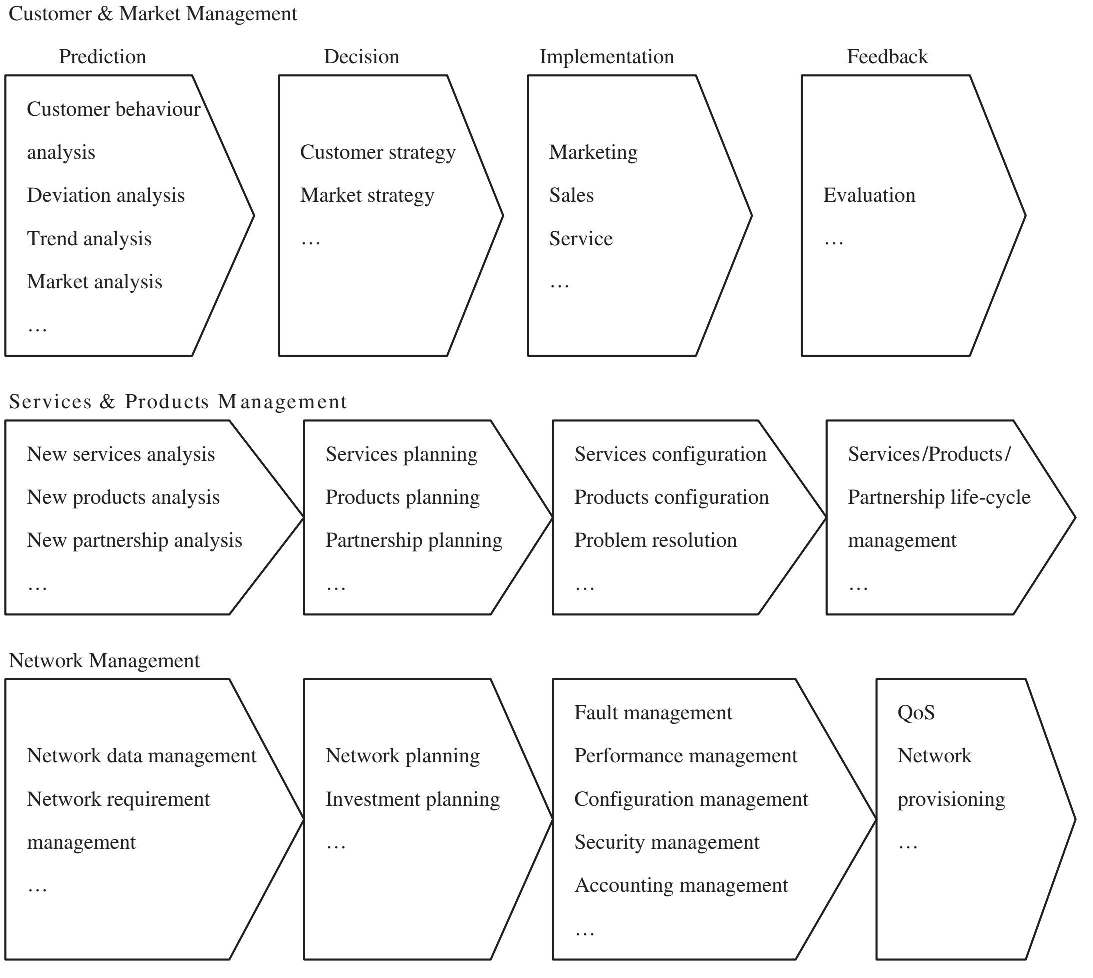

Figure 3: *The framework of a telecom operator's operation management.*

management is the main function of NM, which handles the network resources required for achieving the services/products offered to customers. The area of resource management deals mainly with performance and fault management, and more specifically with dynamic bandwidth management and fault protection mechanisms. Fault management, performance management, configuration management, security management and accounting management are the traditional functions of NM (Stallings, 1998).

CMM is the basis of SPM. According to the relevant analysis of CMM, operators can begin with SPM. SPM is the basis of NM. According to the network resource requirement determined by the volume of total services and products, operators can decide to invest and put forward network development planning. Network resource management must guarantee the service quality to the customer.

3. Overview of techniques in AI

AI has been defined by many experts. Dreyfus and Dreyfus (1986) defined it as 'autonomous thinking machines that are free of human control'. Daniels (1986) defined AI as 'the application of knowledge, thought, and learning to computer systems to aid humans'. Shapiro (Adlassnig, 2002) considered AI as a field of science and engineering concerned with the computational understanding of what was commonly called intelligent behaviour, and with the creation of artifacts that exhibit such behaviour. The more precise definition was given by Feigenbaum and Feldman (1995). They defined AI as the science of artificial simulation of human thought processes with a computer. In this paper, the definition given by Feigenbaum and Feldman is adopted.

As for the subfields of AI, different scholars have different opinions. Pandit (1994) considered that there were six subfields in AI: robotics, expert systems, neural networks, natural language processing, speech recognition, and speech synthesis. Muller *et al.* (1995) classified AI into three components. The first was concerned with high level tasks such as planning and designing (e.g. expert systems, model-based reasoning, constraint satisfaction). The second was distributed artificial intelligence, attempting to solve a problem with a collection of agents rather than with a single agent. The third was less procedural and was more concerned with low level tasks such as perception and pattern recognition (e.g. neural networks, genetic algorithms). Adlassnig (2002) considered that the research areas of AI include natural language understanding, problem solving and search, knowledge representation and reasoning, learning, and vision and robotics. Based upon the above discussion and perspectives, the following AI techniques are mainly available.

Expert systems (ESs) An ES is a computer program that encodes human expertise. A knowledge base and an inference engine are the two basic components (L. Xu & Li, 1993, 2000; L. Xu, 1995; Feng & Xu, 1999a, 1999b; L. Li, 1999a, 1999b; Chen & Xu, 2001; Gao *et al.*, 2001; H. Li & Li, 2000; L. Li & Xu, 2001a, 2001b; L. Xu & Liang, 2001; Yang & Li, 2001; Yang *et al.*, 2001; Sun *et al.*, 2003).

Natural language understanding (NLU) NLU includes natural language processing, speech recognition and speech synthesis. The intent of natural language processing is to develop a language interface to computer systems to process inputs and outputs in languages like English and Chinese. Speech recognition is the processing and interpretation of human voice. Speech synthesis is the computer generation of human-like speech.

Machine learning (ML) Any changes so that the same work can be done more efficiently than previously can be called learning. ML involves the learning ability of the computer. The machine learning algorithm is the main task in ML. Neural networks (NNs) and genetic algorithms (GAs) are the two main machine learning techniques (H. Li & Li, 1999; S. Shi *et al.*, 1999; Chaudhry *et al.*, 2000; H. Li & Xu, 2000, 2001; Zhou & Xu, 2001; H. Li *et al.*, 2003a, 2003b; Zhou *et al.*, 2003; Z. Shi *et al.*, 2007).

Distributed artificial intelligence (DAI) DAI attempts to solve problems in a distributed manner. A DAI system consists of a society of agents; each agent is in charge of a subpart of the problem. Different levels of communication, cooperation and control among the agents might be necessary in order to achieve a coherent global solution (Tang *et al.*, 2001; Feng *et al.*, 2003a, 2003b).

Robotics Robotics focuses on using devices for controlled motion. Robotics is the art of controlling machine movements with computers (L. Xu, 2000).

4. Research methodology

The first step is a literature search using IEEE Xplore. IEEE Xplore provides full text access to IEEE transactions, journals, magazines and conference proceedings since 1998, plus select contents back to 1950, and all the current IEEE standards. Most of the academic publications in telecommunications are included in IEEE Xplore. Using AI and telecommunications as two keywords, our search matched 113 papers out of 1,396,453 documents.

Second, we used ACM Digital Library. ACM delivers resources to the computing profession with leading-edge publications, conferences and career resources. Using AI and telecommunications as keywords, 13 papers were obtained.

Third, we used the Elsevier SDOS/SDOL, Kluwer Online and ABI databases. With AI and telecommunications as keywords, we matched 72 papers.

We also searched the *Proceedings of the Fifth International Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP2006)* and *IFISF 2006: An International Forum of Information Systems Frontiers*, which was published in July 2006.

We kept 63 papers for analysis. They were selected using the following criteria:

- AI is directly applied to telecommunications;
- the application of AI in a certain area of telecommunications is the main topic of the paper;
- the research methodology is well described;
- the research results are available and complete.

All of these 63 papers are involved with the following periodicals and international conference proceedings:

- *Artificial Intelligence*
- *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*
- *AI Expert*
- *Engineering Applications of Artificial Intelligence*
- *IEEE Communications Letters*
- *IEEE Transactions on Vehicular Technology*
- *IEEE Transactions on Evolutionary Computation*
- *IEEE Transactions on Neural Networks*
- *IEEE Journal on Selected Areas in Communications*
- *IEEE Transaction Magazine*
- *Optical Fibre Communications*
- *Computer Networks and ISDN Systems*
- *Speech Communication*
- *Computer Communications*
- *Computer Networks*
- *Telematics and Informatics*
- *Information Economics and Policy*
- *Information and Software Technology*
- *ACM Computing Survey*
- *Communications of the ACM*
- *Information Systems Research*
- *Production and Operations Management*
- *Journal of Systems Architecture*
- *Interacting with Computers*
- *IEICM Transactions of Information and Systems*
- *Omega*
- *Proceedings of the 2003 International Conference on Cyberworlds*
- *Proceedings of the 8th IEEE International Symposium on Computers and Communication (ISCC '03)*
- *Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS '03)*
- *ESANN 2004 Proceedings of the European Symposium on Artificial Neural Networks*
- *Proceedings of the 5th International Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP 2006)*
- *IFISF 2006: An International Forum of Information Systems Frontiers*

5. Results

5.1. Applications of AI in CMM

The application of AI in CMM in a telecom operator's operation management is relatively new. The reason lies in the character of the telecommunications industry and the innovations in this industry. The telecommunications industry has a natural monopoly character. This means that it is difficult to have complete competition in this market. The earlier operators have great advantages over the late and new entrants. It is very difficult for newer entrants to survive if there are no constraints for earlier ones. For the earlier operators, there is no motivation for them to be concerned about customers and the market because of monopoly. But the situation has changed since the 1980s, and anti-monopoly, deregulation, globalization and technology

Table 1: *Application of AI in CMM*

Author(s)	*AI techniques*	*Research result*	*Application areas*
Kamm *et al*., 1997	NLU (NLP, SR, SS)	The potential applications of spoken language interfaces, spoken language processing and the human–computer interface are discussed	Service
Mozer *et al*., 2000	ML	Statistical ML is used to predict churn	Customer behaviour prediction – churn
McTear, 2000	NLU	This paper involves the application of intelligent interface technology in telecommunications	Service
McTear, 2002	NLU	The application of the potential of spoken dialogue technology in telecommunications is analysed, e.g. computer telephony integration in customer services	Service
McBurney *et al*., 2002	ML	Some of the AI techniques can be used to forecast customer demand for new communication services	Trend analysis
Lee *et al*., 2003	ML	ML techniques can been used to predict customer behaviour	Customer behaviour prediction
Au *et al*., 2003	ML	Data mining by evolutionary learning is used to handle customer churn prediction	Customer behaviour prediction – churn
L. Zhang *et al*., 2003	DAI	A mobile-agent-based architecture for a large-scale collaborative virtual environment is proposed to support a large number of concurrent participants in a virtual environment with a large amount of evolving virtual entities	Service
Y. Qiu, 2003	ML	Data mining techniques are used to predict customer churn in telecommunications	Customer behaviour prediction – churn
Ferreira & Vellasco, 2004	ML	Data mining techniques are used to evaluate wireless churn	Customer behaviour prediction – churn
Kim & Chung, 2004	NLU	A new method to extract pitch synchronous cepstrum for robust speaker recognition over telephone channels is proposed	Service
Yan *et al*., 2004	ML	ML techniques can be used to predict customer's behaviour in telecommunications	Customer behaviour prediction
Qi *et al*., 2006b	ML	The prediction effects of decision trees, NNs and Logistic are compared in fixed-line telecommunications	Customer behaviour prediction – churn
Si *et al*., 2006	ML	NNs are used to capture mobile customers' demands	Trend analysis
Qi *et al*., 2006c	ML	The hybrid model of ADTree and Logistic is constructed to predict mobile customers' churn	Customer behaviour prediction – churn
Y. Zhang *et al*., 2006	ML	The hybrid KNN–LR model is designed to predict customer churn in telecommunications	Customer behaviour prediction – churn

Notes: NLP, natural language processing; SR, speech recognition; SS, speech synthesis.

Table 2: *Summary of the application of AI in CMM*

AI techniques	*Percentage*	*Application areas*
ML	11/16 = 68.75%	Customer behaviour prediction, especially churn prediction; trend analysis
NLU	4/16 = 25%	Service, customer touch point
DAI	1/16 = 6.25%	Service

development have all intensified the competition situation in the industry. Now operators have to pay more and more attention to customers and the market. We identified 16 papers from 2000 to 2006, which are shown in Table 1.

ML was used in 68.75% of the papers (11) to predict customer behaviour and trend analysis; NLU was used in 25% of the papers (four) in customer touch point management to achieve more efficient customer communication in customer service. There is one paper using DAI for customer service, which amounts to 6.25% (see Table 2). For the 11 papers in which ML is used, nine papers discuss customer behaviour prediction and two papers discuss customer demand trend. In the nine papers, seven are involved with customer churn prediction research. It can be seen that ML is getting popular in this field; NLU is special for customer touch point service, and DAI is more suitable for customer service.

5.2. Applications of AI in SPM

Thirteen papers were selected for studying the application of AI in SPM (see Table 3). This research field is still undeveloped. Almost all the work in the literature is about services. The concept of 'product' which includes services, brands, prices and so on is discussed. Partnership management still lacks attention in SPM. Some practical work on product management and partnership management has been carried out.

ESs are the most frequently used AI technique in SPM. Among the 13 papers, there are eight papers involving the application of ESs in SPM, 61.54%. DAI is the second most frequently used AI technique in SPM. There are five papers introducing DAI's application in this area and the percentage is 38.46%. ML also has a relatively high application frequency. There are four papers that applied ML, the percentage being 30.76%. Statistically, ESs and DAI are more frequently used in service configuration and ML in service analysis. All the statistical figures are shown in Table 4.

5.3. Applications of AI in NM

NM is the main application area of AI in telecommunications. According to our references, there are five research reviews from the year 1989 to 1997 (Covo *et al.*, 1989; Cubulka *et al.*, 1989; Muller *et al.*, 1992, 1995; Kumar & Venkataram, 1997). In this paper, there are 37 papers involving the application of AI in NM in telecommunications (see Table 5).

Among these papers, 18 papers (50%) discuss the application of ESs in NM; there are 12 papers using DAI in NM (33.33%) and 11 papers (30.56%) present ML in NM. This shows that ESs are mainly used in performance management (PM), configuration management (CM) and fault management (FM) in NM, DAI is generally applied to PM and CM in NM, and ML is preferred for use in PM in NM. As for the exact application areas, ESs are more suitable for fault detection, network monitoring, network diagnosing, network controlling, network resource configuration and so on. DAI is more capable of managing a network in a heterogeneous and distributed environment, especially for adaptive decentralized routing, service provisioning, security mechanisms, network resource configuration etc. ML is used in network monitoring, diagnosing, predicting and optimization etc. For ML, NNs are commonly used for network diagnosing and predicting etc., while GAs are used more in optimization problems in network performance management. The general application of AI

Table 3: *Application of AI in SPM*

Author(s)	*AI techniques*	*Research result*	*Application areas*
Cox *et al.*, 1995	ML	AI/statistical tree growing method is used to identify the operations area where improvements are expected to affect the customer most	Service analysis
Fitsilis, 1995	ES (programming)	An integrated object-oriented ES is development for telecommunication service	Service configuration
Fitsilis, 1996	ES (modelling)	Object-oriented paradigm and AI are discussed to design a complex telecommunication service system	Service configuration
Eberlein & Halsall, 1997	ES	An expert system called Requirements Assistant for Telecommunications Services is developed to help requirements acquisition and early analysis, and encourages specification reuse with the help of a semi-automated negotiation process	Service analysis
Amiri, 1997	ES (modelling)	Some basic computing models are provided, which are the basis to establish an ES for telecommunications services	Service configuration
Magedanz, 1997	DAI	Multi-agents are used in Telecommunication Information Networking Architecture for the unified provision of the future telecommunications and management service within a common distributed processing environment	Service configuration
Adamopoulos *et al.*, 1998	ES, ML, DAI	AI can be used to develop rapid prototyping of new telecommunications services	Service configuration
Kolberg *et al.*, 1999	ES	ES is used to develop an object-oriented telecommunication service framework	Service configuration
Adamopoulos *et al.*, 1998	ES, DAI, ML	Many AI techniques can be used to build a new advanced multimedia telecommunications services system in a distributed and heterogeneous environment	Service life cycle management
Fricke *et al.*, 2001	DAI	A framework of agent-based telematic services system is provided to realize rapid development, deployment and management of agent-based systems and services	Service configuration
L. Zhang *et al.*, 2003	DAI	A mobile-agent-based architecture for large-scale collaborative virtual environment is proposed to support a large number of concurrent participants in a virtual environment with a large amount of evolving virtual entities	Service planning
Kim, 2005	ML	Conjoint analysis technique was used to estimate customer preferences for the International Mobile Telecommunication 2000 service in Korea	Service analysis
Koutsorodi *et al.*, 2006	ES	An expert framework, named Terminal Management System, is established to realize service configuration taking into account network resource availability, user preferences and service requirements	Service configuration

in NM for telecommunications is summarized in Table 6. In some cases, ESs and ML are used together.

5.3.1. The application of ESs in NM In the 18 papers involving ES applications, 55.56% of papers are in the time period from 1988 to

Table 4: *Summary of the application of AI in SPM*

AI techniques	*Percentage*	*Application areas*	
		Application	*Percentage*
ES	8/13 = 61.54%	Service configuration	6/8 = 75%
		Service analysis	1/8 = 12.5%
		Service life cycle management	1/8 = 12.5%
DAI	5/13 = 38.46%	Service configuration	4/5 = 80%
		Service planning	1/5 = 20%
ML	4/13 = 30.76%	Service analysis	4/4 = 100%

Table 5: *Application of AI in NM*

Author	*AI techniques*	*Research result*	*Application area*
Ross *et al.*, 1988	ES	An ES is used to construct an AI-based NM system, named Network Monitoring and Control System	PM
Ashang *et al.*, 1988	DAI	Cooperating intelligent agents are introduced to adaptive decentralized routing in a wide-area network	CM
Sonnenwald, 1988	ES	Frame representation, object-oriented programming and rule-based programming are used to design human–computer interfaces, which provide simultaneous access to a multiple operations system to maintain, test and configure complex telephone networks	PM, CM
Salo & Hamalainen, 1989	ES	An ES is developed to support telecommunications investment	AM
Covo *et al.*, 1989	ES, ML (multiple NNs)	An ESs and multiple NNs are used to construct an AI-assisted, real-time, centralized NM prototype for network monitoring and diagnosing	PM, FM
Shah & Arellano, 1990	ES, ML (NN)	ESs and NNs are used to develop a defence switched network (DSN) system to diagnose anomalies and network traffic, switch status reports and recommend appropriate network controls to the DSN controller	PM
Shimazaki & Takahashi, 1990	ES	An ES is used to develop a network fault management system named NEOPILOT (network operations system for isolation and localization of troubles in networks)	FM
Weihmayer & Brandau, 1990	DAI	DAI research on cooperative distributed problem-solving between dissimilar autonomous agents is used to help telecommunications NM	CM
Silver, 1990	ML	This paper describes NetMan, a knowledge-based program that uses an ML technique, knowledge-based learning, in domain network traffic control	PM
Gingrich & Minden, 1990	ES	MANDOLIN, a communication management ES using a reduced form of the Dempster–Shafer uncertainty theory, is developed to diagnose and control a communications network	PM
Yagi *et al.*, 1991	ES	CAPRIS (Calling Procedure Instruction System) is used to assist the calling party in a telecommunications network to find an appropriate contact point depending on the purpose of the communication	CM
Green & Sims, 1991	ES	An ES, named Satcomms Network Export, is developed to aid fault diagnosis in satellite communication networks	FM

Table 5: *Continued*

Author	*AI techniques*	*Research result*	*Application area*
Liu *et al.*, 1992	ES	A heuristic system for a special problem in a communication network called the T1 problem is designed with bulk facilities	PM
Karunanithi, 1993	ML	An NN is used to model the presence of code churn	PM
Widrow *et al.*, 2004	ML (NN)	Many NN applications are under development in the telecommunications industry for solving control problems	PM
Vlloa *et al.*, 1995	ES	An ES is used as an intelligent controller for a cell site working in a code division multiple access mobile cellular telecommunications system	PM
Dabke *et al.*, 1995	ES	An ES is used to design optical fibre communication links	CM
Lindley, 1995	DAI	Intercommunicating agents are used to construct an architecture for satellite management	PM
Cox *et al.*, 1995	ML	AI/statistical tree growing method is used to identify the operations area where improvements are expected to affect the customer most	PM
Gaitz, 1996	DAI	This paper describes a model based on DAI to manage an intelligent network	CM, PM
Nofal & El-Rabeey, 1996	ES	A real-time object-oriented ES is developed for mobile radio networks	PM
Pitt *et al.*, 1997	DAI	An agent-oriented middleware architecture is introduced for network and service management in telecommunications	PM, CM
Chien *et al.*, 1997	ES	An ES, named Deep Space Network Antenna Operation Planner, is developed to generate antenna tracking plans for a set of highly sensitive radio science and telecommunications antennae. The system can provide the requested services using the allocated equipment	PM, CM
Wills *et al.*, 1998	ES DAI	ES and agents are used to evaluate network serviceability	PM, CM
Lin & Ho, 1999	ES (knowledge acquisition techniques)	A generic ontology-based approach is described to ease the requirement analysis of NM software	PM, CM
Deng *et al.*, 2000	DAI (mobile agent)	A mobile agent is used to establish a network platform and to provide a security mechanism. On this network platform, service providers can provide the new services rapidly, expediently and safely	SM
March *et al.*, 2000	DAI	Mobile computing, intelligent agents and net-centric computing are discussed in heterogeneous and distributed environments	PM, CM
Fricke *et al.*, 2001	DAI	A framework of an agent-based telematic services system is provided to realize the rapid development, deployment and management of agent-based systems and services	CM
Marzo *et al.*, 2003	ES, DAI	A simple but flexible distributed simulator is provided to support NM	PM, CM
Pencolé & Cordier, 2005	ES	A framework for the decentralized diagnosis of large-scale discrete event systems is described to monitor a real telecommunications network	PM

Table 5: *Continued*

Author	*AI techniques*	*Research result*	*Application area*
Le *et al.*, 2005	DAI ML (GA)	The combination of mobile agent technique and GAs is used to solve the dynamic routing and wavelength assignment problem in wavelength division multiplexing networks	CM, PM
Jafargholi *et al.*, 2006	ML	A GA for optimization of the beam formed in a linear array antenna is used. The goal is to achieve a –30 dB null of the pattern with the capacity to steer the null angle over the whole frequency band	PM
Wedde & Farooq, 2006	DAI	Agent-based routing algorithms are provided to realize adaptive and efficient utilization of network resources in response to changes in the network catering for load balancing and fault management	CM
Vroblefski & Brown, 2006	ML (GA)	A grouping GA for registration area planning is provided to ensure universal service and increased quality of service by performing routine control functions	PM
Zwierzykowski & Piochowiak, 2006	ML	Heuristic algorithms are used to find the cheapest spanning tree between a source code and a group of destination nodes (multicast connections)	PM
Afsari, 2006	ML	GAs are used to find the optimal power distributed network	PM

Table 6: *Summary of the application of AI in NM*

AI techniques	*Frequency*	*Percentage*	*Application area*	*Exact application*
ES	18	50%	PM, CM, FM	Fault detection Network monitoring Network controlling Network resource configuration etc.
DAI	12	33.33%	PM, CM	Network control Multi-services management Network resource management Distributed and heterogeneous NM etc.
ML	11	30.56%	PM	Network monitoring Network control Network optimization etc.

1993, 33.33% of papers are from 1994 to 2000 and 11.11% are from 2001 to 2006. This shows that ESs play an important role in early NM, which is the main application of AI in telecommunications. As time goes by, the research interest of ESs in NM has decreased. One reason causing this change is the essential transformation in telecommunications during this period. The ability to provide multiple customer-oriented services determines the competitive result. The interests of the operators and scholars have shifted to keep up with the competitive requirement. On the other hand, after years of development of AI, more and more mature AI techniques are being used in NM. This can be demonstrated by the fact that the application areas of ESs in NM have narrowed down from 1988 to 2006, but some new problems in NM have been solved by other AI techniques. ESs are mainly used in the network monitoring

Table 7: *The application of ESs in NM*

Year	*Ratio in the total references*	*Application areas*	*Ratio in the ES references*	*Contents*
1988–1993	10/18 = 55.56%	FM PM CM AM	3/10 = 30% 6/10 = 60% 2/10 = 20% 1/10 = 10%	Fault diagnosing Network monitoring Network controlling Network restoration Invest management
1994–2000	6/18 = 33.33%	PM CM	5/6 = 83.33% 4/6 = 66.67%	Quality of Service Network monitoring Network diagnosing Network resource configuration
2001–2006	2/18 = 11.11%	PM CM	2/2 = 100% 1/2 = 50%	Network monitoring Network diagnosing
1988–2006	100%	FM PM CM AM	3/18 = 16.67% 13/18 = 72.22% 7/18 = 38.89% 1/18 = 5.56%	PM CM FM AM

Table 8: *The application of DAI in NM*

Year	*Percentage*	*Application areas*	*Ratio in the DAI references*	*Contents*
1988–1993	2/12 = 16.67%	CM	100%	Adaptive decentralized routing; service provisioning; facility allocation; distributed NM automation system etc.
1994–2000	6/12 = 50%	PM CM SM	5/6 = 83.33% 4/6 = 66.67% 1/6 = 16.67%	Service management in intelligent networks; NM in heterogeneous and distributed environment etc.
2001–2006	4/12 = 33.33%	PM CM	2/4 = 50% 4/4 = 100%	Network routing and control; adaptive and efficient network resource management etc.
1988–2006	100%	PM CM	7/12 = 58.33% 10/12 = 83.33%	CM, PM

and diagnosing areas in which they are more suitable. Generally, PM is the most suitable application area in NM for ESs. The other application areas are CM, FM and accounting management (AM) in turn. The application of ESs in NM is shown in Table 7.

5.3.2. The application of DAI in NM In the 12 papers involving the application of DAI in NM, 16.67% of papers were published from 1988 to 1993, 50% were from 1994 to 2000 and 33.33% were from 2001 to 2006. The trend shows that the application of DAI in NM is increasing. The main allocation areas of DAI are CM and PM of NM. Multi-services management systems are one of the important applications of DAI in CM, which includes service design, service configuration, service development, service deployment, service provision, service control, service billing, quality of service and all the sections in service life cycle management. Adaptive and efficient network resource management is another side of DAI's application in CM. PM of intelligent networks is a hot application of DAI in NM, including dynamic routing,

Table 9: *Application of ML in NM*

Year	*Percentage*	*Application areas*	*Contents*
1988–1993	4/11 = 36.36%	PM	Network monitoring and diagnosing; network control; code churn prediction etc.
1994–2000	2/11 = 18.18%	PM	Network control; network diagnosing etc.
2001–2006	5/11 = 45.45%	PM	Dynamic routing and wavelength assignment; optimization of network resource management etc.
1988–2006	100%	PM	Network monitoring and diagnosing; network control etc.

Table 10: *Application of AI in telecommunications (1)*

Application areas	*Quantity of papers*	*Percentage*
CMM	16	24.24%
SPM	13	19.70%
NM	37	56.06%
Total	66	100%

Table 11: *Application of AI in telecommunications (2)*

AI techniques	*Quantity of papers*	*Percentage*
ES	26	35.14%
ML	26	35.14%
DAI	18	24.32%
NLU	4	5.41%
Total	74	100%

admission control, traffic engineering and so on. The statistical results for DAI in NM are shown in Table 8.

5.3.3. Application of ML in NM In the 11 papers about the application of ML in NM, 36.36% were published from 1988 to 1993, 18.18% were from 1994 to 2000 and 45.54% were from 2001 to 2006. It seems that the application of ML in NM is stable during these years. One interesting phenomenon is that the NN method is used more commonly than the GA method before 1995, while the GA method is used more frequently than NNs after 1995. Maybe this is related to the development of networks in telecommunications. As the scale of the network grows more and more quickly, the number of services it offers increases on a larger scale, and NM becomes more and more difficult. The optimization of network resource management seems more important than ever. Thus, GAs are more frequently used in recent years. Among all 11 papers, ML is used in PM in NM. The exact applications can be generalized as in Table 9.

6. Discussion and conclusion

Our research shows that AI's first main application area in the telecommunications industry is NM, the second is CMM and the third is SPM. In the 63 papers, 37 are about the application of AI in NM, which covers 56.06% of all papers included in this study. Sixteen are about the application of AI in CMM, which covers 24.24%, and 13 are about the application of AI in SPM, which covers 19.7%. Several papers involve more than one AI technique. For statistical convenience, each of them was counted once for each layer of telecom operation management. Therefore, the total paper samples become 66, as Table 10 shows.

ESs and ML are the two AI techniques that are used most frequently in telecommunications, followed by DAI and then NLU. In our research, 26 papers cover the application of ESs and ML in telecommunications. The total percentage covering ESs and ML reaches 70.28%. Eighteen papers involve the application of DAI in telecommunications (24.32%). Four papers are about the application of NLU in telecommunications, which counts for 5.41%. Table 11

Table 12: *Application of AI in telecommunications (3)*

Year	*AI techniques*			
	ES	*ML*	*DAI*	*NLU*
1988–1993	10	4	2	0
1994–2000	12	5	8	2
2001–2006	4	17	8	2

Table 13: *Application of AI in telecommunications (4)*

AI	*Application areas*		
	CMM	*SPM*	*NM*
ES	0	8	18
ML	11	4	11
DAI	1	5	12
NLU	4	0	0

shows the results. Also, some AI techniques have been included in more than one paper. Each of these papers was counted once for each AI technique. Therefore, the number of papers is 74.

ML and DAI are the two most promising AI techniques that are applied to telecommunications. From 1988 to 2006, the employment of both ML and DAI has been increasing. It is expected that NLU will play a more important role than at present in the development of computer telephony integration in customer relationship management. The proportion of the application of ESs in telecommunications will change in the future. The above trends are described in Table 12.

Different AI techniques are suitable for different application areas in telecommunications. ESs are more useful for NM for monitoring, diagnosing and controlling networks. ML is more suitable for CMM and NM. Using ML for predicting customer behaviour and market trend analysis in telecommunications is a relatively new topic, although this has been a reasonably developed research area in other industries. ML is usually integrated with ESs for network control and optimization. DAI seems more powerful in NM for realizing distributed and dynamic NM. In recent years, DAI has become more and more popular for applications in SPM, especially service deployment. DAI is also applied to customer service to help with customer self-service. NLU enhances the efficient and low-cost communication between human and machine in customer service. Table 13 provides more details.

AI techniques have been widely used in telecommunications for more than a decade. It can be seen that the telecommunications industry is one of the most important areas for AI applications. It is expected that AI, as well as the related, emerging, new intelligent systems technology, will be part of the most powerful tools for further promoting the future development of the telecommunications industry sector (Z. Li & Xu, 2003; G. Qiu *et al.*, 2003; S. Xu *et al.*, 2003; M. Zhang *et al.*, 2003; L. Xu *et al.*, 2005, 2007; Luo *et al.*, 2007; Zang & Fan, 2007). On the other hand, the development of telecommunications will also be a driving force to impel the development of AI.

Although we tried our best to search as many relevant papers as possible, some important papers may be left out in this study. However, it is expected that our research result can serve as a reference for AI research in telecommunications.

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The authors

Jiayin Qi

Dr Jiayin Qi was born in 1973. She obtained her Bachelor's degree in mathematics in 1996 and Master's degree in computer science in 1999 from Lanzhou University, Lanzhou, Gansu, China. She obtained her Doctor's degree in management science in 2002 from Xi'an Jiaotong University, Xi'an, Shaanxi, China. She is the first author of *Evaluation, Modeling and Decision Theory of Customer Value* (Beijing University of Posts and Telecommunications Publishing Press, Beijing, China, 2004) and *The Theory of Customer Relationship Management* (Knowledge and Property Right Press, Beijing, China, 2006), and the second author of *Customer Lifecycle Relationship Management in the Telecommunication Industry* (Beijing University of Posts and Telecommunications Publishing Press, Beijing, China, 2004). Her areas of interest include service systems, service management and telecommunications operation. Dr Qi is a member of the IEEE. She is also the Assistant Director of the Key Lab of Information Management and Information Economy, Ministry of Education of the People's Republic of China.

Feng Wu

Dr Feng Wu is an associate professor at the School of Management, Xi'an Jiaotong University, Xi'an, China. His research interests include decision support systems and knowledge management.

Ling Li

Dr Ling Li teaches operations management and technology, electronic supply chain management and other courses at Old Dominion University. Dr Li's research interests include health service management, supply chain management, enterprise resource planning, enterprise information systems, the impact and application of information systems on operations management, e-business, knowledge-based systems, and production planning and control.

Huaying Shu

Huaying Shu is a professor at the School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing, China. His research interests are management information systems and telecommunications management. He is the Director of the Key Lab of Information Management and Information Economy of the Ministry of Education of the People's Republic of China.