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Health Delivery Systems – A Case for Multi-Agent Systems

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***Abstract*—Health delivery systems, involving patients, physicians, health service providers, medication suppliers, medicare, and policies, etc., are a typical complex distributed systems problem. This paper analyses the characteristics of health delivery systems, reviews common coordination mechanisms, and proposes the synergization of multi-agent systems to tackle the complexities of health delivery systems.**

Keywords—health delivery systems, system of systems, multi-agent system, synergization

I. INTRODUCTION

With the development of technology and under the push of demands of the public, health delivery systems have continuously developed. First of all, digitalization level has developed rapidly. 3G and other modern communications and information technologies, including internet and intranet, wired and wireless communication networks have widely been applied in health delivery systems, including Picture Archiving and Communication Systems (PACS), Hospital Information System (HIS), and Laboratory Information System (LIS), medical function application systems, etc., which effectively improve the modernization level of health delivery systems [1].

Secondly, the service flow for health delivery systems is continuously optimized. In Europe and USA, flow-oriented management is widely used in health delivery institutions. In order to make effective use of the health resources and meet the demands of patients there has been a move that common cases are serviced in the community clinics of proximity while serious cases are serviced in hospitals [2].

Thirdly, modern management methodologies are implemented and have achieved successful experiences in some areas, including vendor-managed inventory (VMI), distribution for pharmacy, and online procurement, etc. For instance, cooperative game was used to analyze the relationship between physicians and patients, as well as the effect by adopting incentives to improve their relationship [3]. The cost-benefit method was used for public health services assessment [4].

Moreover, to tackle the complexities of health delivery systems the conception of synergization has emerged in the health delivery field. For instance, in 2004 the Health Ministry of Singapore launched "electronic medical record communion network", in which civics and patients are provided with fast, convenient and inexpensive comprehensive medical examination and treatment. The supply-demand balance problem of medical resources was addressed in Japan by practicing the shift-diagnosis system and providing confederated services by health institutions. In 2003, a regional communion for medical service was implemented at Texas in USA. A significant reduction of treatment costs and increased utilization of medical resources were acquired in the experimental area. This regional communion also establishes the connection between hospital emergency, health administration department, and disease control centers to effectively enhance the synergization capability to deal with emergency events, and further improve the health level and quality of life. In China a regional synergization medical demonstration project, funded by the National Science and Technology Support Program of the 11th Five-Year Plan, aims to achieve region-wide sharing of medical resources.

II. ANALYSIS OF HEALTH DELIVERY SYSTEMS

Health delivery systems comprise a number of systems, collaborative and competitive, and functions and services are provided through the interactions between systems and the environments.

[5] suggests to build a “harmonious health delivery systems”. Namely, health delivery systems make the harmonious interactions between subsystems (internal harmony), and develops harmonious interactions between the systems and environments (external harmony).

At macro level a health delivery system has many systems. Within each system there are a number of subsystems which further form a system chain with different behavioral characteristics, as shown in TABLE I.

III. TOWARDS MULTI-AGENT-BASED HEALTH DELIVERY SYSTEMS

Health delivery systems are a typical complex distributed systems problem and face many challenges.

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TABLE I. SYSTEM CHAINS AND BEHAVIORAL CHARACTERISTICS OF HEALTH DELIVERY SYSTEMS

System Chain	Service Systems	Functions	Characteristics
Supply Chain	Health delivery Resource System	Disease Classification and Gradual Treatment, Regional Synergetic Treatment, Manufacture and Supply of Pharmacy and Medical Equipment, Third-Party Logistics Services	Competition, Negotiation
Technology Chain	Health delivery Technology Cooperation System	Shift-Diagnosis, Telemedicine and Diagnosis, The Treatment of Puzzle Diseases, Health Data Sharing	Collaboration
Economy Chain	Health delivery Economy System	Cost Accounting, Medicare & Cooperative Medicare in Rural Area, Economic Compensation	Competition, Negotiation
Quality Chain	Health delivery Quality, Intendance and Safeguard System	Medical Professional Ethics, Industry Criterion, Service Standards, Health Statistics	Restriction, Astriction
Social Value Chain	Health Delivery Social Value System	Social Benefits, Citizens' Livelihood Engineering, Health Culture	Restriction, Astriction
Administration Control Chain	Health delivery Policy System	Government Regulation, Health Care Legislation	Prompting, Intendance, Administration
Service Chain	Health delivery Service Flow System	Patient-Orientation, Health Centering, Reconstruction of Flow and Coordination	Cooperation, Reinforcement
Emergency Chain	Health Delivery Emergency System	Public Medicine, Prevention and Early Caution of Vicious and Infectious Diseases	Agility, Integration

- The imbalance of resources in distribution and structure: The limited health resources are concentrated in the economically developed areas and large cities, while there are shortages of health resources in the western region especially in rural areas.
- Diversification and personalization of demands: On the one hand, public demand for health services include medical care, prevention, health protection, healing, health education, consultation, as well as health delivery services cross regions (such as migrant population). On the other hand, health delivery services are moving towards patient-orientation and health centering.
- Diversity of health delivery systems: Health delivery services, as complex systems cover the central and local governments, social forces, as well as health delivery services providers, and involve such technical problems as resources allocation, service optimization, medical insurance, and macroeconomic policies, etc.

In order to address these challenges for a typical complex distributed systems problem, multi-agent systems (MAS) provide new view and methodology.

An agent is a physical or logical intelligent or semi-intelligent physical object and can provide functions. Agents can be processes, people, robots, expert systems, or enterprises, and their profiles can be described by knowledge, belief, commitment and ability. Agents can provide functions such as cooperation, coordination, and conflict resolution. Agents are dispersive with high degree of autonomy in physics or logic. In order to achieve a common mission or to reach a certain goals agents congregate together by complying with a protocol to solve the problem, which is beyond the ability or knowledge of a single agent. Agents interact and cooperate with each other, and with the environments through perception-action [6].

A multi-agent system is an organically organized system consisting of a number of agents which exercise communication, coordination, self-learning, and reorganization [7]. Collaboration is a core issue of multi-agent systems. Multi-agent systems can achieve goals through the collaboration of a number of agents. Collaboration can break the constraints of resources, environment and time, and harmonize the interactions to solve the problem encountered [8].

Multi-agent systems provide new methods and solutions for health delivery systems. Health delivery services comprise many systems which form supply chains, value chains, economic chains, technology or social chains, etc., respectively. Multi-agent systems can capture the complex characteristics of health delivery systems such as system distribution, autonomy and interactions, etc.

IV. MULTI-AGENT SYSTEMS MODEL FOR HEALTH DELIVERY SYSTEMS

Multi-agent systems provide an effective way to solve complex systems, and following the function definition, encapsulation, and abstraction, a multi-agent system can be

built for health delivery systems. Entities in health delivery systems can be abstracted and encapsulated into agents with corresponding functionalities, respectively. Entities in health delivery systems include governments, various health service providers, the public, as well as other relevant units or entities. Based on their interactions and the impact of environments, these entities form an organically coordinated health delivery systems.

Multiple agents respectively represent different entities, comply with a common coordination mechanism, exchange real-time data with the environments, timely coordinate various resources both inside and outside the system, and form a self-adaptable, self-organizing and organically synergized system to complete overall goals and missions of the system.

To be generic for different systems of health delivery systems and to effectively manage and organize the complex classes of agents, role-based agent-oriented software design technology may be applied to build multi-agent systems for health delivery systems.

Agents are designated with their different roles, respectively, and a pair format is set up for agents, i.e., (AgentNo, RoleType). These agents playing different roles implement different functions and tasks in different systems of health delivery systems.

The roles played by these agents include:

- Health delivery provider Agent: community (village) clinic Agent, (town) center infirmary Agent, (county) general hospital Agent, epidemic prevention centers Agent;
- Personnel Agent: physician Agent, nurses Agent, medical technician Agent, Patient Agent;
- Resource Agent: CT Agent, Ward Agent, operation Agent, pharmacies Agent;
- Function Agent: diagnosis Agent, inspection Agent, healing Agent, consultation Agent;
- Administration & Surveillance Agent: quality Agent, Statistics Agent, Planning, Agent;
- Medicare & Finance Agent: medicare Agent, insurance Agent, cooperative medicare in rural area Agent, Finance Agent;
- System Agent: interface Agent, database Agent, electronic medical records Agent, public announcement Agent, registration Agent.

Those agents play different roles based on their interactions and constitute service chain, value chain, supply chain, etc., respectively.

Furthermore, a nested architecture for health delivery systems may be established, where services and functions, resource utilizations, customer demands and other factors are taken into account in order to improve the efficiency of the system.

V. COORDINATION MECHANISMS FOR HEALTH DELIVERY SYSTEMS

A. Conventioanl Coordination Mechanisms

Coordination mechanisms can influence agents' behaviors by restricting their interactions. The conventional coordination mechanisms include the contract net, auction mechanism, as well as the model of results sharing.

Contract Net model is a basic coordination mechanism and widely applied [9]. The negotiation process between manager and bidder includes announcing mission information, forming bids, submission of bids, evaluating bids, informing of the results, as well as the acknowledgement and the information exchange process [10]. Leader-Follower collaboration mechanism is a variant of contract net, and reaches cooperation by centralized control. Based on the contract established by bargainers agents can carry out the mission or assign tasks, and each agent can be a main bidder or a manager for the subordinate contract, finally the agents can form a system with embranchment structure [8][11].

Simulated Trading Algorithm [12] is an optimized contract net mechanism. Following the repeated negotiation processes each time the negotiation cycle can produce negotiation results, and the later negotiation cycle based on the last cycle will further optimize the results.

Double Bids Based Protocol [13] is based on contract net model by calculating real and virtual bids based on the same resources, respectively. It aims to meet multiple users' demands for the same resources. However, the difference of both real and virtual bids is tiny.

Third-party Negotiation Protocol [14], is also known as auction mechanism. Both supplier and bidder do not directly negotiate the task and mission, but depend on the auction with the third-party participation to complete negotiation. Negotiation information is exchanged and communicated through a third party as an intermediary. The mechanism can achieve the mission assignment among agents through the auction by third-party participation. However, the collaboration between both supplier and bidder are temporary, one-off collaboration, and a loose partnership. Agents under this mechanism are competitive each other, and there is no mutual communication information. Therefore, the agent with competitive ability most likely wins the bid [11].

Collaboration by results sharing is for multi-agent collaborative work [15], where the results are sharing with each other to save resources and improve accuracy and speed. In this mechanism, all agents' are equal to each other. They negotiate the mission through the blackboard in accordance with their ownership of resources, and decide the commitment mission amount by sharing the resources [8] [11]. Blackboard is a typical result sharing mechanism also known as parallel negotiation mechanisms [16]. Blackboard is a common structure with results sharing and is a collaborative approach widely used in multi-agent systems.

B. Comments

Because of the complexities of the interactions between systems and environments, the performance of health delivery

systems heavily depends on effective coordination mechanisms of multi-agent interactions. The synergization of multi-agent system is crucial for health delivery systems. Horizontally, health delivery systems require the synergization between service flow, organizational management, government regulation, and the synergization between governments, hospitals, patients and other entities. Vertically, health delivery systems require the synergization between various levels of health delivery providers, pharmacy suppliers, information operators, as well as medical insurance.

The conventional coordination mechanisms are facing new challenges in health delivery field:

- Firstly, most of the coordination mechanisms are used in manufacturing, supply chain, logistics fields, to which the characteristics of health delivery services have none similarity;
- Secondly, the collaboration results are not optimal. For example, contract net ignores the implicit relationship between agents and environment, agents' abilities are limited, and resources and mission assignment are difficult to achieve optimize.
- Thirdly, the negotiating agreement is a continuous adjustment and constantly repeated negotiation process. With the impacts of data transmission and decentralized control, it is difficult to reach agreement quickly at the overall system level.

Therefore, it is imperative to develop effective coordination mechanisms suitable for health delivery systems.

According to the characteristics of health delivery systems, coordination mechanism for health delivery systems should be a dynamic mechanism which is established based on multiple objectives, different resources, constraints and optimization, and various typologies of agents.

On the one hand, agents in health delivery systems have multiple goals. For example, Patient Agent has goal representing by a set U={treatment time, treatment cost, medical technology, service level, other}. On the other hand, health delivery service providers have their resources representing by a set V={technology, medical equipment, expenses, other}.

With the aid of a collaboration mechanism of health delivery systems agents can realize a process that a goal (patients) with different diseases, different values, and different risks can effectively match the resources providers (hospitals) with corresponding resources, technologies, the expenses, and finally achieve the system-wide maximization of the overall performance with lowest cost.

On the other hand, with the variety of the environments, cooperation mechanisms should be able to adjust and adapt itself quickly, namely dynamics. For example, with the reimbursement policies of medicare, the resource set and goal set of agents in health delivery systems can be timely updated.

VI. SUMMARY

Health delivery systems are typical complex distributed systems. The relationship among entities of health delivery systems is cooperative game, and there are obvious difference and contradiction among entities, in terms of, e.g., service quality and treatment costs, and standardization services and personalization demands. Health delivery systems implement the functions and services and meet the demands for the public based on multi-agent cooperation and competition.

Multi-agent systems can be an effective approach to tackling complex characteristics of health delivery systems. Based on the multi-agent system architecture the health delivery systems can realize synergization among systems involved and environments, further optimize the health delivery flows, enhance the efficiency of utilization of limited resources, and improve the overall level health services. A coordination mechanism for the system's synergization to be proposed should focus on the nature of health delivery systems, and completely realize the collaborations in the system, and emphasize the competition and cooperation, the surveillance and constraints, and the safety and criteria in the supply chains, value chains, economic chains, technology or social chains, respectively.

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