Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

AGENT-BASED SIMULATION OF ENTERPRISE COMMUNICATION NETWORK

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ABSTRACT

In this paper, we consider an agent-based simulation of dynamic enterprise organization and communication networks. Along with recent progress and popularization of Information Technology, social sciences have been experiencing great advances in survey methodology. It has become possible for researchers to utilize huge social data with computers. However, there have been only conceptual studies in business school and few quantitative studies about enterprise organizations. In a survey of an enterprise, we evaluated strategic organization changes with graph/network analysis of the communication network constructed from email transaction data. Moreover, there is strong business needs to know how activities change according to an organization transformation. Utilizing the agent-based approach, we have constructed a dynamic model and simulation of communication over an organization structure. The result of the simulation indicates the power distribution for link degrees which is also observed in the real world as universal characteristics of the scale-free network.

1 INTRODUCTION

In this paper, we consider an agent-based simulation of enterprise communication network. Observing enterprises from a view point of social human relationship, we notice that there are a couple of networks co-existing (Figure 1). These networks are mutually affected and important for business and personal activities in the enterprise.

To perform business activities strategically with strong leadership, usually there is a definite organization hierarchy in an enterprise. The organization hierarchy starts from the top node which consists of board of directors and CEO, going through several level of managers, and arrives at employees. Such an organization structure can also be observed in Government and Army. Organization studies are motivated to achieve business goals efficiently with strategic design and transformation of organization along with management policies, enterprise cultures and business environments.

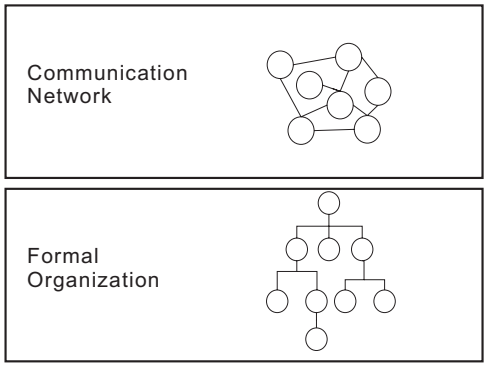

Figure 1: Communication Network and Formal Organization

On the other hand, employees' good climate and innovation with flexible collaboration across organization become important in services business and R&D.

Recent Computational Organization Theory (Carley 1998) investigates communities from the view point of agents and network. Also, along with the recent findings (for example, Barabasi 2002) on widely observed characteristics among natural or artificial networks, new network studies such as small world network (Watts 1999), scale-free network, and evolving network attract researchers' interests.

In today's dynamically changing business environment, it is important to know how employees' activities change according to organization restructuring. The agent-based approach is now becoming a powerful tool to investigate such a dynamic complex system with heterogeneous interacting entities. By modeling complex entities as software agents, the agent-based simulation can reproduce complex macro phenomena intuitively. In a series of works (Mizuta and Steiglitz 2000, Mizuta and Yamagata 2002, Mizuta, Steiglitz and Lirov 2003) , we have considered agent-based approach. In this paper, we will construct a dynamic agent model of the communication network and a prototype of organization simulation.

2 COLLABORATIVE ORGANIZATION ANALYSIS

For business collaboration, we can use various kind of communication method from traditional face-to-face meeting and telephone to computational email, instant messaging and groupware. It is still difficult to gather all such activities.

In this paper, we consider the transaction obtained from email send/receive log. Together with the organization network, we can analyze the communication network in enterprises.

In traditional social sciences, researchers have to investigate various communication among examinees by direct interviews or questionnaires. Such a human survey is so troublesome and time-consuming that available data is small. By using email transaction log which is automatically stored on email servers, we can obtain enormous communication data easily.

In the next section, we will introduce a survey in one enterprise before and after a strategic organization change. With business activities, it is important to take into account positions in the strategic enterprise structure. We have analyzed huge email communication as described above. From a viewpoint of privacy, we aggregated the transaction data as the communication flow between departments so that a particular employee cannot be traced.

We developed a tool to aggregate the communication flow and to calculate network indices. As the preprocess, the tool aggregates email transaction data between lowest-level departments (units) to link information between strategic groups (nodes) which we want to investigate.

For the analysis of aggregated network, we use simple network indices. Currently, this tool evaluates Input/Output Degree, Distance, and Closeness. With an adjacent matrix $A = (a_{ij})$ where a_{ij} is the communication frequency between node n_i and node n_j and a distance matrix $D = (d_{ij})$ where d_{ij} is the geodesic distance between n_i and n_j, Degrees and Freeman's Closeness are written as follows:

$$InDegree(n_i) = \sum_j a_{ji},$$

$$OutDegree(n_i) = \sum_j a_{ij},$$

$$Closeness(n_i) = \frac{1}{\sum_j d_{ij}}.$$

We also consider Power index and Faction (subgroup) with UCINET.

3 SURVEY RESULTS

In this section, we briefly introduce an example of survey on communication network and organization changes. We investigated one company with consultants (IBM Business Consulting Services KK) using communication and organization data and tools described in the previous section. Especially, we pay our attention on the recent strategic organization change. We made an analysis with a node definition created for this purpose and observed changes appeared in the communication network.

The organization structure can be represented by 2-dimensional matrix (product groups in rows and client sector groups in columns). Before the organization change, the matrix structure was not balanced. Because relationship within a product group was dominant, customer need to contact various separated product groups. The focused organization change is intended to strengthen another direction (client sector relationship) to balance the matrix structure and to provide one face services.

We investigated changes in Degrees of the communication network along these two directions. Results are shown in Figure 2.We can observe a significant increase of the communication along sector from the graph. On the other hand, this change does not cause a undesirable side effect on the communication along product.

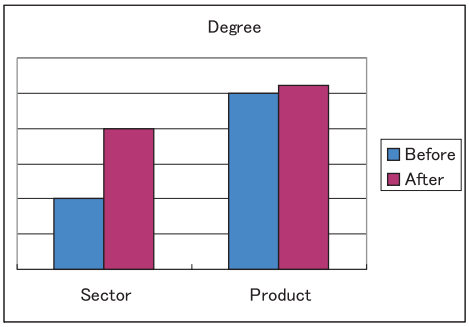

Figure 2: Degree Change in Product and Sector Direction

Next, we analyzed changes in Total Closeness (Figure 3). This result shows that the whole organization network becomes more condensed. In addition, the distribution of Degree sorted by order of degree are shown in Figure 4 with a log-log scale.

This result indicates a power law distribution and that the communication network has a characteristic of the scale-free network. It is known that many other self-organized fractal networks have similar property.

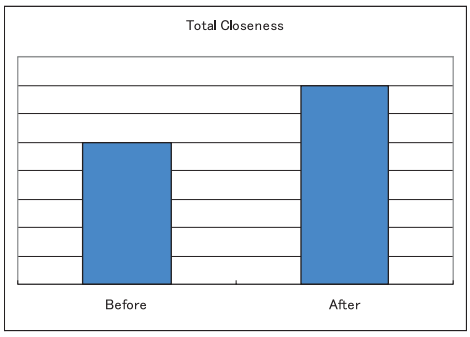

Figure 3: Total Closeness Change

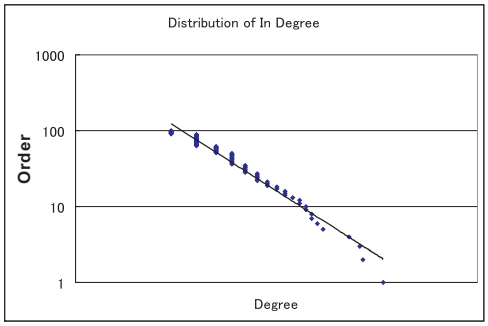

Figure 4: Power Law in Degree Distribution

4 DYNAMIC SIMULATION FOR ORGANIZATION

In this section, we introduce our agent-based simulation for organization and communication. In previous survey, we utilized a few snapshots of email transaction to evaluate an enterprise. However, we need more dynamic analysis to evaluate organization changes and optimize the organization structure. So, we consider a dynamic model for communication in an organization with heterogeneous interacting agents.

In our organization analysis, we investigate strategic organization structure and ad-hoc communication network. For dynamic simulation model, we consider these dual related networks, too. That is, we simulate the formulation of the communication network over the given organization structure. Organization structure is given as a set of nodes and reporting links. In this paper, we use randomly generated tree structures for organization. It can be easily extended to general network structure including matrix organization.

Both the organization network and communication network are implemented as subclasses of general Network class and possess same set of nodes. There is one central agent which manage these networks and control the simulation. And there are participants agents each of which is related to one node.

As previous simulation models, simulation process proceeds with RFB message from central to participants which contains organization information, and BID messages from participants to central which contain communication information. The organization structure is shown in the GUI window of the central agent (Figure 5) and the aggregated communication network in Watcher agent (Figure 6). Each link of the communication network has a gray scale color; small amount of transaction with white and large amount of transaction with black.

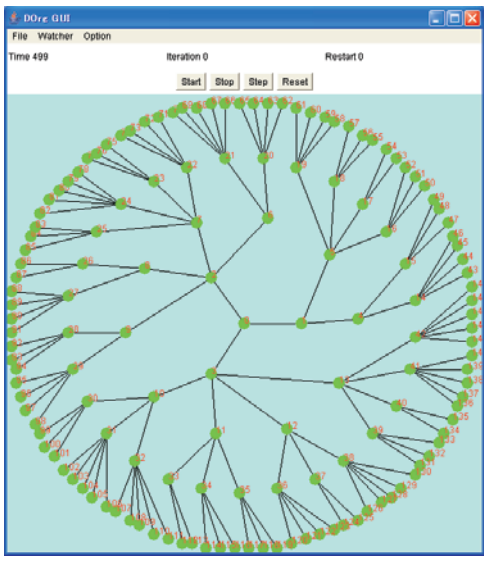

Figure 5: GUI Window of Agent-based Simulation with a Randomly Generated Organization Structure

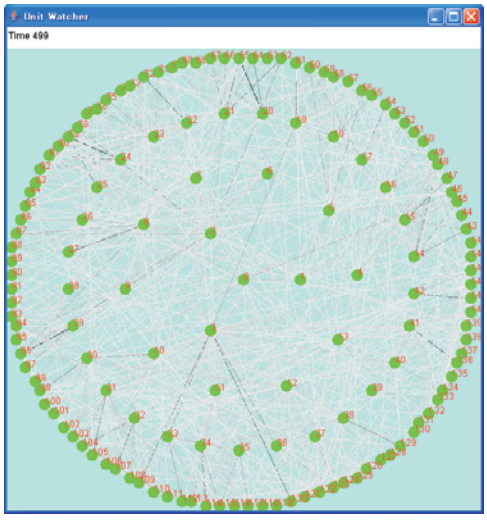

Figure 6: Simulation Screenshot of Aggregated Communication Network

We consider following dynamic model for N participant agents.

1. Agent i has communication probability c_i for one RFB (or time t).
2. Destination agent j of a communication is selected from (a) neighborhood on organization structure, (b) send/receive historical data, or (c) random node, with respective probabilities (P_n, P_h and P_r):
   (a) From the organization structure, agent i evaluates the distance d_{ij} along the formal network. Typically, the nearest neighbor (e.g. direct parent or child node) has the largest probability.
   (b) The agent has fixed time range of memory M about send/receive communication and picks up destination from the communication history during $[t-64 : t-1]$.
   (c) The agent may select an destination from the set of other all agents randomly.
3. The central agent collects all communication pair (i, j) received from sender agent i and notifies it to receiver agent j so that agent j updates its memory.

The communication network in this model has a set of node i $(0 \leq i < N)$ and a set of communication link L_{ij} with an aggregated link amount.

For our prototype simulation, we set communication probability c_i uniform randomly in a range $[0.05 : 0.30]$. The destination preferences are $P_n = 0.4$, $P_h = 0.3$, and $P_r = 0.3$, and the memory range $M = 64$.

Hereafter, we denote a set of neighbor agents with distance d on the formal organization structure as d-neighbor. The survey results (Figure 7) indicate that communication frequency for d-neighbor is almost constant if d is smaller than the depth of organization hierarchy. In other words, the number of agents in d-neighbor increases exponentially with distance d, but in the same time, the communication frequency to an agent with distance d decreases exponentially (Figure 8) in the same rate so that the total communication amount to d-neighbor is balanced.

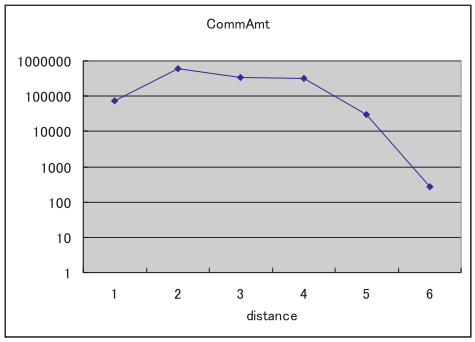

Figure 7: Communication Amount for Node Distances

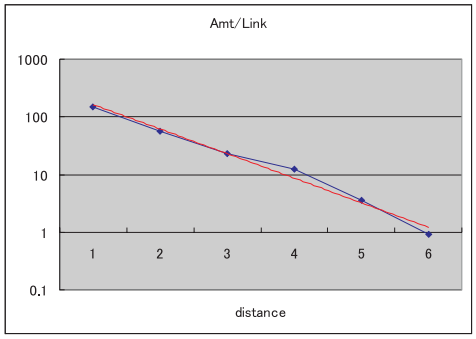

Figure 8: Communication Amount per Link for Node Distances

In the simulation, we select distance d uniform randomly $1 \leq d \leq D$, where $D = 4$ is the depth of organization hierarchy. The distribution of InDegree for simulation results at $t = 3000$ is shown in Figure 9. InDegree is a number of communication link to a node whose amount is larger than the cut threshold 5. We sort InDegree and plot its values (x-axis) and orders (y-axis) both with log scale. The graph shows slowly decreasing line which means the power-distribution as scale-free network. On the other hand, we also show the results with only random communication in Figure 10. Without organization neighbor preference and historical memory, InDegree drops quite rapidly similarly.

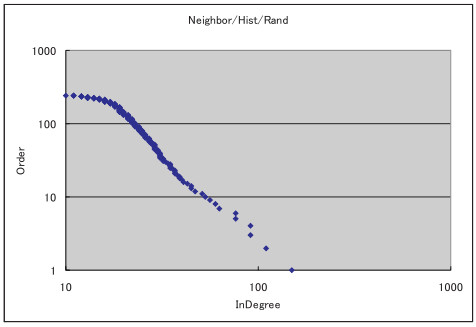

Figure 9: InDegree Distribution with Simulation Including Neighbor Structure and Historical Memory

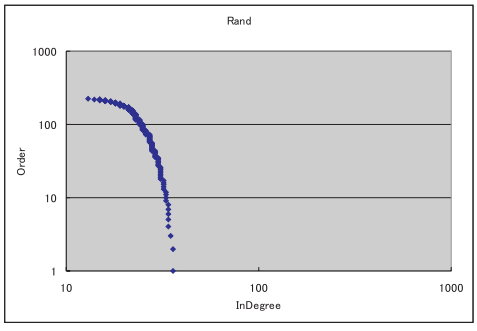

Figure 10: InDegree Distribution with Random Selection

5 CONCLUDING REMARKS

In this paper, we have introduced a dynamic organization simulation with agents. We consider the communication network over enterprise organization. By constructing the dynamical model of the communication network and comparing the reproduced network with survey results in real enterprises, we are able to understand the nature of ad-hoc communication network. We have proposed a prototype model and simulation of dynamic communication on the enterprise structure. The results reproduced the power distribution of Degree similarly as the observed data in a real enterprise. It is important to utilize such a universal characteristics to verify plausibility of a model.

We assume the neighbor preference for destination selection based on the survey results. It is left as a future work to investigate the dynamic/historical preference to predict effects of organization changes.

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