TECHNICAL DIFFUSION BY SOCIAL MEANS: AN AGENT BASED FRAMEWORK FOR DISTRICT HEATING

Marco Remondino
Department of Computer Science
University of Turin
Italy
E-mail: remond@di.unito.it

KEYWORDS
Social Networks, Software Agents, Simulation, Diffusion.

ABSTRACT

The spreading of certain innovations can't be modelled just by taking into accounts pure technical issues; sometimes the forecasts made with a statistical or process based model, which considers just the engineering or financial aspects (i.e.: production process, activity decomposition, scale economies, product life cycle and so on), prove to be inaccurate or even wrong. This is commonly the case of cellular telephones, air-cooling systems, personal computers and so on, fields in which some external influences have led to diffusion results which are very different from the initial previsions obtained with classical prevision tools. The purpose of this work is to examine the diffusion of an emerging technical innovation: the district heating. The spreading of this technology shouldn't be affected by phenomena like fashion – as happened with cellular phones - and its adoption can't be considered a status symbol. Although, there are some other influences which can't be taken into account by a traditional process based or statistical simulator, i.e.: the effects of individual perception about savings, ecological impacts and so on.

INTRODUCTION

District heating is a system for distributing heat generated in a centralized location for residential heating requirements. The heat is often obtained from a cogeneration plant; more generally district heating is the name assigned to the creation of an infrastructure with pipes, buried in the ground and filled with warm water, to satisfy concentrated heat requirements on local heat markets. Heat is normally supplied to the pipes by retrieving and refining heat that other entities have no further use for and by using fuels or natural heat that end-users cannot use easily.

Examples of such heat sources are heat retrieved from thermal power processes (also known as combined heat and power), industrial processes and refuse incineration plants as well as geothermal heat and wood waste. District heating is normally delivered to satisfy heat requirements in cities for heating and hot water in residential, commercial, and public buildings. The heat requirements must be concentrated in order to attain low distribution costs.

This technology is diffused in north European countries and is also spreading to the rest of Europe; in particular the analysis in this paper is conducted with the support of AEM – Iride Turin, i.e.: the electrical company of Turin, a city located in north-western Italy.

A technical and statistical analysis can give hints about how the district heating is spreading and will spread on the territory, but can't answer to some very important questions, i.e.: how can incentives and benefits increase the adoption of district heating? How can phenomena like word-spreading, or the perceived convenience, or the concerns about environment and nature influence the diffusion of this technology?

In this paper an agent based framework is described, which should address such questions and others, and that could be applied to other similar technologies, like solar photovoltaic panels and so on.

AGENT BASED MODELING AND SIMULATION

Agent Based Modelling is the most interesting and advanced approach for simulating a complex system: in a social context, the single parts and the whole are often very hard to describe in detail. Besides, there are agent based formalisms which allow to study the emergency of social behaviour with the creation and study of models, known as artificial societies. Thanks to the ever increasing computational power, it's been possible to use such models to create software, based on intelligent agents, which aggregate behaviour is complex and difficult to predict, and can be used in open and distributed systems.

In Franklin and Graesser (1997) we read that:

An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future.

Another very general, yet comprehensive one is provided by Jennings (1996):

…the term [agent] is usually applied to describe self-contained programs which can control their own actions based on their perceptions of their operating environment.

Agents themselves have traditionally been categorized into one of the following types (Woolridge and Jennings, 1995):

- Reactive
- Collaborative/Deliberative
- Hybrid

When designing any agent-based system, it is important to determine how sophisticated the agents' reasoning will be. Reactive agents simply retrieve pre-set behaviours similar to reflexes without maintaining any internal state. On the other hand, deliberative agents behave more like they are thinking, by searching through a space of behaviours, maintaining internal state, and predicting the effects of actions. Although the line between reactive and deliberative agents can be somewhat blurry, an agent with no internal state is certainly reactive, and one that bases its actions on the predicted actions of other agents is deliberative.

The agents used in this paper are reactive, but organized in the form of a MAS (multi agent system), which can be thought of as a group of interacting agents working together or communicating among each other. To maximize the efficiency of the system, each agent must be able to reason about other agents' actions in addition to its own. A dynamic and unpredictable environment creates a need for an agent to employ flexible strategies. The more flexible the strategies however, the more difficult it becomes to predict what the other agents are going to do. For this reason, coordination mechanisms have been developed to help the agents interact when performing complex actions requiring teamwork. These mechanisms must ensure that the plans of individual agents do not conflict, while guiding the agents in pursuit of the goals of the system..

SOCIAL NETWORKS AND CONNECTIONS

A social network is defined as "a set of nodes - e.g. persons, organizations - linked by a set of social relationship - e.g. friendship, transfer of funds, overlapping membership - of a specific type" (Laumann, et al., 1978).
Any kind of network can be described in terms of a graph, composed of nodes and a set of lines, edges, joining the nodes. In a mathematician's terminology, a graph is a collection of points and lines connecting some (possibly empty) subset of them. The points of a graph are most commonly known as graph vertices, but may also be called nodes or simply points. Similarly, the lines connecting the vertices of a graph are most commonly known as graph edges, but may also be called arcs or lines.

The study of graphs is known as graph theory, and was first systematically investigated by D. König in the 1930s (Gardner, 1984). Graphs come in a wide variety of different sorts. The most common type is graphs in which at most one edge (i.e.: either one edge or no edges) may connect any two vertices. Such graphs are called simple graphs and are the ones we'll use in our analysis. The edges of graphs may also be imbued with directedness. A normal graph in which edges are undirected is said to be undirected. Otherwise, if arrows may be placed on one or both endpoints of the edges of a graph to indicate directedness, the graph is said to be directed. The connections here represent the level of "friendship", and serve the purpose of transmitting the opinions about the new technology.

In the present work the graph used to represent the social network linking the agents together is bi-directed, i.e. each edge points on both directions as once. This seems realistic, since we can imagine our network as a group of people who know each other. If A knows B, then it's quite obvious that B knows A in turn; we don't voluntarily consider those situations in which a subject disseminates her/his opinion to others and isn't touched by their decisions (e.g.: advertisement, political campaigns, and so forth). That's because we suppose that this sort of dissemination comes "a priori", i.e. before our analysis starts; we are now interested in studying how a set of agents mutually connected into a network can influence one another and come to a final overall result.

The only exception is that of some "special" agents, i.e.: the property managers, who are connected to the other agents via a mono-directional link (since they are supposed to spread their knowledge towards the people living in the condominiums, but not to be affected in turn by their opinions).

THE SIMULATION FRAMEWORK

A number n of macro-agents is built, that represent the condominiums; each of those is composed of a random number of agents (where the range can be set with min/max or can obey to a normal distribution, given an average).

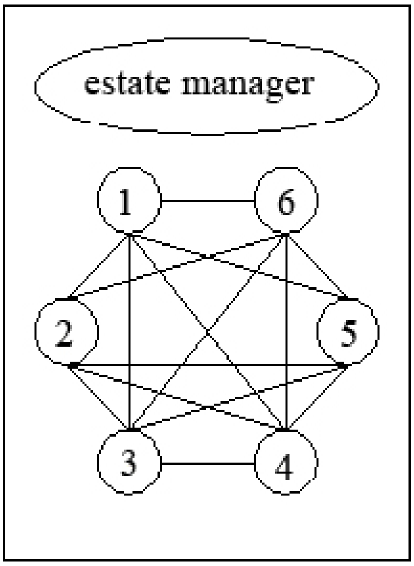

Figure 1: the Condominium and the Agents living in it

The agents belonging to the same condominium will be connected by a network; the links will feature a random weight, with a modifiable threshold. The network has the purpose of transmitting the information about the technology, that's coded through a function describing the perception of the real phenomena. The perception is surely derived from the real saving allowed by the new technology, but not only that; there could be a bias, representing other factors, like trustfulness towards the company, ecological reasons and so on. The agents will spread their own perception on the network, to the other agents connected to them and this will be modified according to the weight of the specific individual link. Each macro-agent will also feature a property/estate manager, who could also be shared by two or more condominiums, thus constituting a bridge among different macro-agents and, indirectly, among the agents involved.

A second link among the macro-agents is represented by social networks among the agents living in different condominiums. We can metaphorically depict these links as friendship, job or family relationship and so forth.

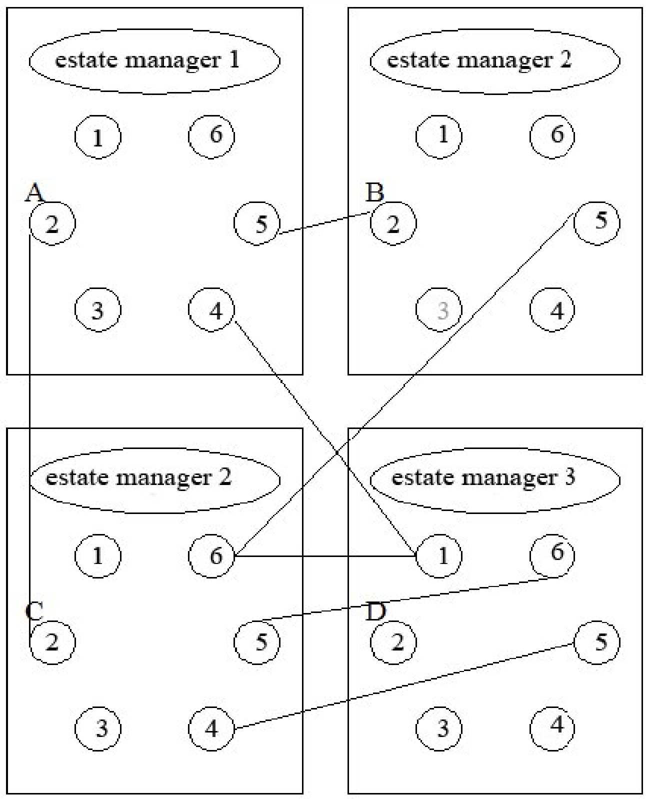

Figure 2: Different Condominiums Linked by Social Relations among Individuals

The important aspect is that only agents are connected, not the condominiums; agents represent people, so they can be connected somehow, while condominiums can be considered "connected" among them if and only if the people living in them know each other.

Since the focus is how the district heating can spread thanks to social relations among people, the model, through repeated execution, can show the diffusion over time, by changing just one parameter at a time, while leaving the others unchanged (*ceteris paribus*).

The Parameters in the Model

Here follows a list of the parameters used in the simulation:

1) Total number of condominiums
2) Average number of agents per condominium
3) Average or maximum weight for the links among the agents living in the same condominium
4) Percentage of condominiums already reached by the new technology
5) Cost for the installation (una tantum)
6) Average saving allowed by the new technology
7) Perception BIAS (1:double perception, 0:perfect perception, -1:inverse perception, 2:random perception)
8) Average or maximum weight for the links among the agents living in different condominiums
9) Satisfaction Threshold (0: always satisfied, 1: satisfied only if perfect conditions occur)
10) Requested majority to adopt the district heating for the condominiums (percentage)

These parameters can be changed by the user at the beginning of the simulation, in order to mimic, as much as possible, the real world. Some parameters are very general (such as "Average number of agents per condominium", "Average or maximum weight for the links among the agents living in the same condominium", "Cost for the installation" and so on). They should be set accorging to the values observed on samples taken in the city where we want to set the study.

Other parameters, such as "Satisfaction Threshold" and "Perception BIAS" are more difficult to determine; they are derived from the Cognitive Sciences and define how a single person perceives the environment and the innovations. It is possible to assume that almost nobody has a perfect perception, since this would be similar to the "Homo oeconomicus" assumption in the Neoclassical Economics, i.e.: a stylized and ideal type of the instrumentally rational individual. More realistically, people have a perception BIAS, that's the general tendency of a person to view a situation in a particular light based upon the method of socialization that they were brought up with, their personal experience, their knowledge and so on.
A technician could have almost a perfect perception about how convenient a technical innovation can be, but an average person can't.
Besides, not all the individuals are satisfied about something at the same threshold; somebody could be happy to save 100€ per year, while others don't even bother for that amount of money.
That's why these two parameters must be set according to some general observations and common sense.

Model Iterations and Steps

In this subsection an overview about how the model works is given. Here follows the sequence of steps performed during the simulation:

1) The first step is the adoption of the new technology by a number of condominiums
2) The new technology has some installation costs, and brings a positive or negative saving compared to historical data
3) These values will be perceived by the agents living in the condominiums, but filtered by their personal BIAS (which takes into account different income, ecological awareness and so on)
4) Each agent will spread through the social network her/his own perception, and the agents linked with her/him will form their own opinion, according to the weighted average of the received opinions
5) According to the "satisfaction threshold", the agents will individually decide whether to adopt or not the new technology
6) Once all the agents in a condominium have formed their own opinion, according to the requested majority, the condominium will adopt the new technology or not yet. The next step will be a loop from point number 2).

There is not a metaphorical correspondence between the steps and time units. Since in six months many condominiums can pass to the new technology, we could realistically think at heach step as one month time.

RESULTS AND COMMENTS

Several experiments have been run on the model, by changing the parameters in order to mimic different scenarios. Two are the main parameters that affect the diffusion over time: a different connection level and a different perception level. In particular, since we are dealing with a single city, we we can expect a saturation level, that’s a threshold beyond which it’s not possible to go (i.e.: a limited number of agents can be reached by district heating, since a limited number of people live in a city). So we aspect an higly connected network to increase the diffusion speed over time (we can think to small villages as an example).
This threshold is represented by the parameter called “Total number of condominiums” that multiplied per “Average number of agents per condominium” gives a good approximation of the total number of agents in the simulation (not exact, due to sampling effects). On the graphs, the new adoptions per time step are shown.

In figure 3, the results with a low perception index and a loosely connected network are shown, while in figure 4 there are the results with the same low perception but with an (unrealistically) fully connected network. As noticieable in the comparison in figure 5, the fully connected scenario leads to a faster adoption of the new technology, followed by a steady trend, when almost all the condominiums are reached.

In the next three figures (6, 7 and 8) the Fully Vs Loosely networks are tested in a high perception environment. Since the new technology brings positive savings, the scenario with a loosely connected network seems less noisy and more regular. The scenario with a fully connected network, on the other end, is that in which in few steps all the condominiums adopt the new technology, after which the adoption rate falls to zero.

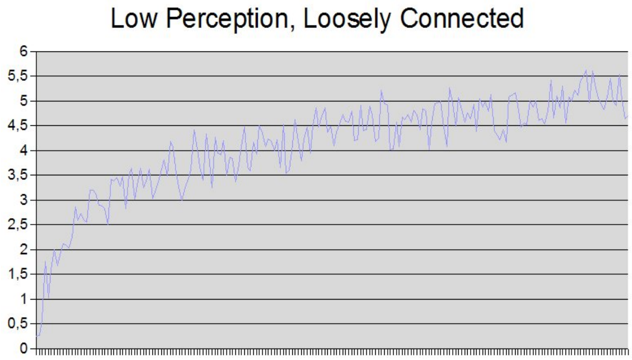

Figure 3: Low Perception and Loosely Connected Network

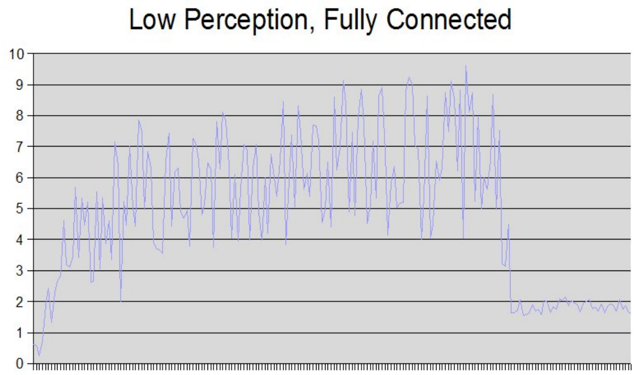

Figure 4: Low Perception and Fully Connected Network

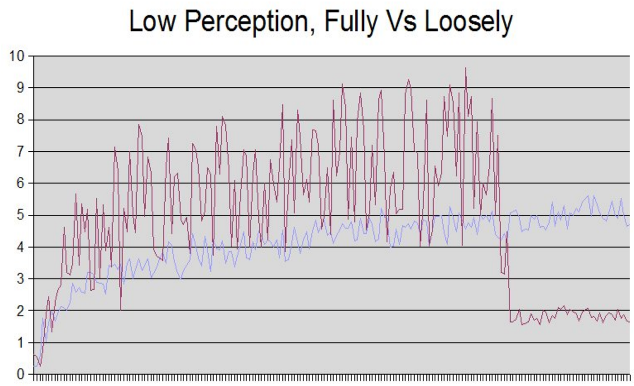

Figure 5: Comparison among Loosely and Fully Connected with Low Perception

Considering the real data from AEM Torino, the most realistic situation is the LP-LC one.
In the real-world, normalized data, there is a logarithmic-like growth of the diffusion, stabilizing at 5x the initial value and then slowly decreasing (when most of the city is reached).
In the real world, as to the district heating technology, the individual perception is thus to be considered lower than the real economical benefit; that’s probably because there are not fashion issues connected with this technology.
Very different from this is the case concerning the spreading of the cellular phones (whose diffusion resembles the initial path of HP-FC curve in figure 7), also because, differently

from the case of district heating, a single person can change cellular phone over time, and thus the market won't saturate easily.

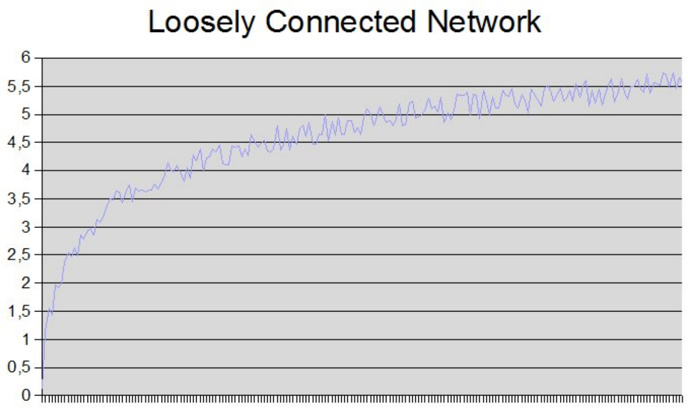

Figure 6: High Perception and Loosely Connected Network

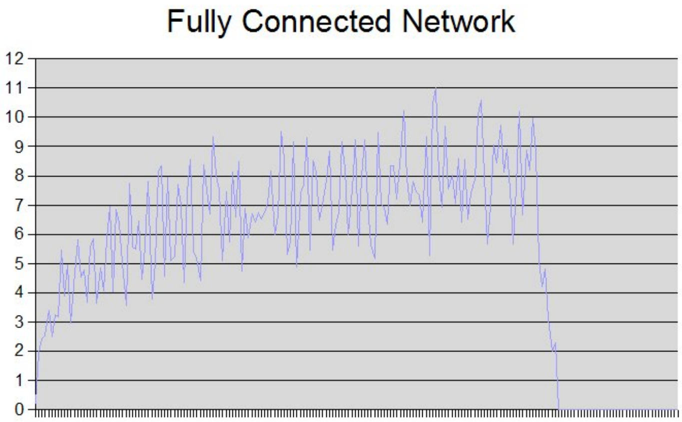

Figure 7: High Perception and Fully Connected Network

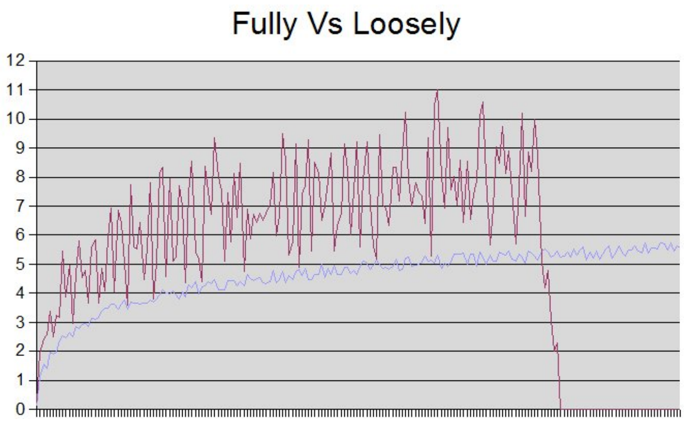

Figure 8: Comparison among Loosely and Fully Connected with High Perception

CONCLUSION

An agent based framework to test the social impact on technology diffusion has been presented; in it, a certain number of agents are connected by some sort of relation, by a social network. As a testbed for the model, the case of District Heating is analyzed: in it there is no fashion involved, but just economical decisions related to the money that can be saved with the new technology, over time.

The core parameters of the model are the level of perception, describing how well the real impact of the new technology is perceived by the agents, and the level of connection of the social network connecting the agents.

An empirical validation, comparing data coming from the simulation to real ones, shows that for district heating the perception is "low" and the social network is loosely connected. This means that some kind of innovations, like those in which fashion is not an important factor, spread slowly even if they are technologically relevant and bring savings.

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AUTHOR BIOGRAPHY

MARCO REMONDINO got his Master Degree in Economics at the beginning of 2001, with 110/110 cum Laude et Mentione. He then started a PhD in Computer Science, during which he delved into theoretical studies about the structure of different software agents, namely the reactive and deliberative (BDI) ones. He completed his PhD in January 2005.

After that, he was awarded a two-year research scholarship from ISI Foundation, for the Lagrange Project on Complex Systems, during which he applied agent based paradigms to design several models in different scientific fields, namely Game Theory, Biology, Economics and Enterprise Simulation.

At present, he holds a post-DOC research grant from University of Turin, Department of Computer Science.

His main research interests are Agent Based Model-ling, different paradigms for agents and their integration, computer simulation, Social Systems, emergent properties for Complex Systems, Social Networks, Action Selection, agent learning through Neural Networks, Genetic Algo-rithms, Classifier Systems, paradigms of Reinforcement Learning, Data Mining, validation of models.