무선통신기술의 진화: 무선통신산업 경쟁하의 기술 경로 탐색

Evolution of Wireless Technologies: Exploring the Technology Trajectory in Competitive Wireless Industry

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요 약

이 논문은 무선통신 산업에 있어서 경쟁하의 무선통신기술의 진화 경로를 밝히고자 하였습니다. 저자는 과거 자료를 분석하기위해 로가렛분석(Loglet Analysis) 기법을 도입하였습니다. 초기 연구결과는 기술경로상에서 네트워크 효과와 대체효과가 존재한다는 것입니다. 이 논문의 결과는 무선통신 서비스 사업자에게 그들의 네트워크에서 이익을 최대화할 수 있는 방향과 차세대 무선통신기술 이전 전략을 수립하는데 이용될 수 있을 것입니다.

키워드 : 경쟁기술, 기술진화, 3세대 무선통신, 네트워크효과, 대체효과

Ⅰ. Introduction

Today's modern network industry is challenging with a variety of rapidly evolving network technologies. One such evolving network technology is wireless technologies which have already experienced two generations over a very short period of time. In the early 1980s, the first generation (1G) wireless technology was based on analog only for voice communications. By the mid-1990s, the second-generation (2G) wireless technology emerged as digital suitable for data communications. Now, the 3G/4G wireless technology is becoming reality as high-speed multimedia services.

Understanding technological trajectory is an essential step for the development and assessment of new technologies. There are several methods available to analyze the technological trajectory, such as market surveys, historical analogy, time series models, economic models, diffusion models, economic cost models, and discrete choice models. We use the diffusion model which is concerned with the spread of a new technology in the marketplace, especially *Loglet Analysis* tool. It is a new technique to analyze the complex diffusion process of products or technologies competing in market. In our study, *Loglet analysis* is used to analyze the wireless technologies.

The paper aims on the structuring and analyzing of technological trajectory in wireless industry from the first generation (1G) to the second generation (2G) and towards next generation (3G/4G). This paper investigates the evolution of technologies in wireless networks to place them in the proper context. For an analysis of these technology evolutions, we introduce the *Loglet Analysis* tool which is one of the most popular tools to analyze the technological trajectory field (Dolfsma and Leydesdorff, 2009).

Ⅱ. Literature Review

New technologies often present increasing returns (Arthur, 1989) through market expansion, product price reduction (Rosenberg, 1982; Saviotti and Trickett, 1992; Cowan, 1990) and network externalities (Rohlfs, 1974; Katz and Shapiro, 1994; Economides, 1996; Brynjolfsson and Kemerer, 1996). Other studies (Oren and Smith, 1981; Farrell and Saloner, 1985; Katz and Shapiro, 1992) focus on the dynamics of technology adoption under increasing returns. Some studies (Cowan, 1991; Dosi, 1993) further explored and popularized this dynamics of product selection by establishing models of competing technologies.

In general, when economists explain about the *substitution effect* (Böhm and Haller, 1987), they are referring to the fact that as the price of one good or service rises relative to another, consumers will tend to favor the latter, cheaper option. If people are genuinely indifferent to whether they eat chicken or beef for dinner, a rise in the price of steaks, for instance, may cause some to choose drumsticks instead.

There have been few studies (Fisher and Pry, 1971; Blackman, 1974; Peterka, 1977; Sharif and Kabir, 1976; Norton and Bass, 1987) in the technological substitution literature of a series of technological substitutions. The most intense and interesting competition may indeed be taking place between the two newest technologies, but there are a number of examples of simultaneous competition of more than two generations As each innovation is studied in finer detail, it is often clear that the process is evolutionary, not revolutionary. The process of multilevel substitution is central to the development of the model we propose.

Newer technologies are continually replacing older ones (Fisher and Pry, 1971). The time interval between successive generations of high-technology electronic products has been demonstrated to be relatively brief in comparison with the time interval between replacing technologies using historical norms (Norton and Bass, 1987). As the time interval between technologies decreases the importance of under- standing the impact of recent technologies on earlier ones increases (Peterka, 1977). No matter what their advantages, newer technologies are not adopted by all potential buyers immediately. Rather, a diffusion process is set into motion (Blackman, 1974).

Katz and Shapiro (1985) provides the following definition of Network Effect, a network effect is the increasing utility that a user derives from assumption of a product as the number of other users who consume the same product increases.

The adoption of new technology creates positive or negative effects, which are called Network Effect. Positive network effects are obvious. One example of positive network effects is increasing returns (Arthur, 1989) through the usage of a larger distribution network. If adoption by different users is complementary, so that each user's adoption payoff, and his incentive to adopt, a positive network effect increases as more others adopt. While negative network effects beyond lock-in also exist. Negative network effects result from resource limits. An example for negative network effects is Lock-in Effect (Liebowitz and Margolis, 1994), which prevents firms from leaving an adopted technology, though the usage of a new technology would be advantageous in the future.

Another phenomenon of network effects is Path-Dependency. Path dependency theory was originally developed by economists to explain technology adoption processes and industry evolution. The theoretical ideas have had a strong influence on evolutionary economics (Nelson and Winter, 1982). It simply means how the set of decisions one faces for any given circumstance is limited by the decisions one has made in the past. As its economic point of view, Arthur (1989) derives a path dependent process from a random-walk model, where two types of agents have each preference for two types of various technology standards. Agents consume decisions, however, not only depend on their own preference, but also on the overall preference of the other agents.

Ⅲ. The Model and Hypotheses

3.1 The Model

Many quantitative studies of technology evolution (Kim and Ahn, 2006) have adopted a single generation model to simulate the diffusion pattern of demand, such as logistic s-curve (Altinkemer and Yilmaz, 2008; Kucharravy and Guio, 2007; Pry, 1971; Marchetti, 1980; Meyer, 1994). However, this traditional approach only considers the diffusion of the new technology itself, not taking into account new generations, which can replace the one just developed. Recently a new technique, *Loglet Analysis*, is developed to analyze the complex diffusion process of products or technologies competing in market (Meyer *et al.*, 1999). For example, we can think of different modes of transportation (horses, trains, cars, airplanes, etc.) as competing in the same market. Loglet Analysis which is developed by Meyer-Yung-Ausubel (1999) at the Rockfeller University refers to the decomposition of growth and diffusion into S-shaped logistic components.

Loglet Analysis comprises two models: the first is the component logistic model, in which autonomous systems exhibit logistic growth. The second is the logistic substitution model, which models the effects of competitions within a market.

First, the component logistic model assumes that a population N(t) of individuals grows or diffuses at an exponential rate α until the approach of a limit or capacity k slows the growth, producing the familiar symmetrical S-shaped curve. This model can be expressed mathematically by the following ordinary differential equation (ODE) which specifies the growth rate $\frac{dN(t)}{dt}$ as a nonlinear function of $N(t)$:

$$\frac{dN(t)}{dt} = \alpha N(t)(1 - \frac{N(t)}{k})$$

For values of $N(t) << k$, equation closely resembles exponential growth. As $N(t) \rightarrow k$, the feed back term slows the growth to zero, producing the S-shaped curve. It is easy to solve the logistic ODE to find the function $N(t)$ which satisfies equation:

$$N(t) = \frac{k}{1 + e^{-\alpha t - \beta}}$$

where a is the growth rate; β is the location parameter which shifts the curve in time but does not affect the its shape; and κ is the saturation level at which growth stops.

While κ can be easily seen in a graph, α and β can not. Accordingly, we replace them with two related metrics, the midpoint and growth time. We define the growth time, Δt, as the length of the interval during which growth progresses from 10% to 90% of the limit k. Through simple algebra, the growth time is $\Delta t = \frac{\ln(81)}{\alpha}$. We define the midpoint as the time t_m where $N(t_M) = \frac{k}{2}$. Again simple algebra shows $t_m = -\frac{\beta}{\alpha}$, which is also the point of inflection of $N(t)$, the time of most rapid growth, the maximum of $\frac{dN(t)}{dt}$.

The three parameters κ, Δt, and t_m define the parameterization of the logistic model used as the basic building block for *Loglet Analysis*

$$N(t) = \frac{k}{1 + \exp\left[-\frac{\ln(81)}{\Delta t}(t - t_m)\right]}$$

Second, let's introduce competition and then measure its effect. So, we assume that there are several technologies to compete each other in the market. The logistic substitution model generates substitution curves, $L_1, L_2, \cdots, L_n$. These curves follow the market share through the three substitution phases: logistic growth, non-logistic saturation, and logistic decline. The first step in generating these curves from the logistic substitution model is to fit a curve to the growth phase of each technology. Reiterating from above, because we are working in the Fisher-Pry transform space, then

$$\ln\frac{l_i}{1 - L_i} = -\frac{\ln 81}{\Delta t_i}(t - t_{mi})$$

is linear, and we can estimate the parameters for such a curve with linear regression. As before, Δt_i is the characteristic growth time for the ith technology, and t_{mi} is the midpoint of the ith technology's period of growth or decline.

Note that for the logistic substitution model, we use a logistic with only two parameters, because the third parameter, saturation level (k) has fixed at 1, or 100%. Without the introduction of a new technology, the last technology in the growth phase would grow to a 100% market share. If a new technology is introduced, its growth must come at the cost (primarily) of the leading technology, causing it to saturate and decline.

The growth and decline phases can be represented by logistic curves, but this is not the case for the saturation phase. Because only one technology(L_s) can be saturating at a time, its market share can be calculated by subtracting the sum of the shares of all the other technologies-which must be known, since they must be either growing or declining-from unity (100%):

$$L_i = \sum_{i \neq} L_j$$

How do we know when each phase begins or ends? If

$$y_i(t) = \ln\frac{L_i(t)}{1 - L_i(t)},$$

then the termination of the saturation phase comes at time t at which

$$\frac{y_i''}{y_i'} \text{ is at a minimum}$$

When the saturation phase for a technology ends, it proceeds directly into its decline phase, and the saturation phase for the next technology immediately commences. The two parameters for the logistic decline phase of the curve are given by:

$$\Delta t_i = \frac{\ln(81)}{y_i'(t)}$$

$$t_{mi} = \log \frac{(y_i(t) - \frac{\ln(81)}{\Delta t} t}{\frac{\ln(81)}{\Delta t}}$$

3.2 Hypotheses

Wireless technology evolution is investigated by presenting the historical evolution of wireless network technologies, i.e., the transition from first generation (*1G*) analog, voice-only communications to second generation (*2G*) digital, voice and data communications, and, further, to third generation (*3G*) wireless networks and the Internet.

In the evolution of wireless technologies, we assume that existing technologies grow logistically to their saturation points, and then are replaced by a superior technology that conforms to the market's new requirements. To visualize the impact of new technologies on wireless market shares, this study's parameters are based on a logistic scale, rather than using regression analysis. A logistic scale is useful when little or no data is available, as is the case for new technologies seeking to be market leader.

Hypothesis 1: *The evolution of wireless technologies has followed the traditional logistic S-curve pattern, but the introduction of new generation technologies does not decrease immediately the demand of the existing old generation technology market.*

Technology substitution is a process by which an innovation is replaced partially or completely by another in terms of its market share over a period of time. In this process one technology replaces or substitutes for another with varying degrees of direct one-to-one competition. The replacement of technology may be instantaneous, or it may take considerable time (Marchetti, 1995). The advancing technology may seem to be evolutionary or revolutionary depending upon the take-over time period and each successive generation of the technology may have a new niche by creating new customers (Meyer *et al.*, 1999).

The new technology influences the diffusion of both new and old generation technologies. Some times while one technology is replacing an old technology, a still newer one is replacing it and multiple substitutions take place. In such situations of uncertainty, a study of technology substitution is important for network service providers, whose efforts and huge investments are at stake.

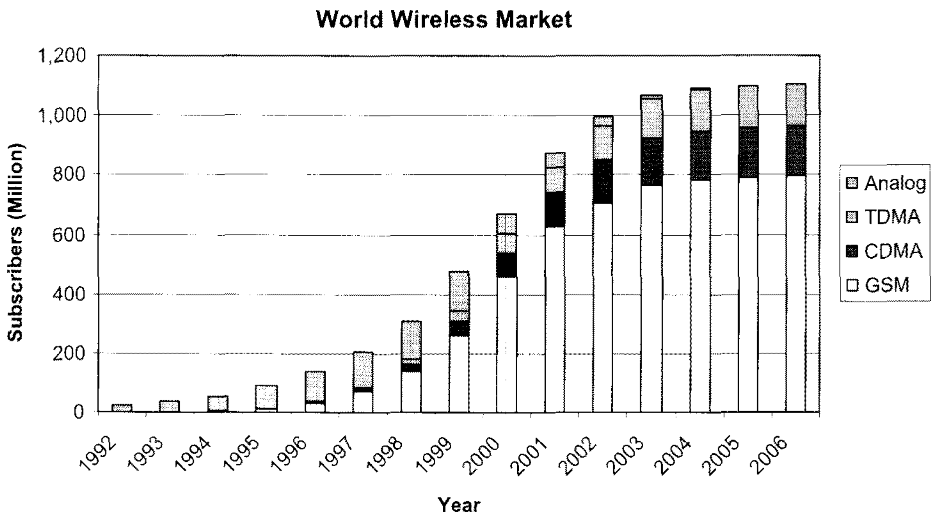
Currently three wireless technologies are offered competitively in the US; TDMA, CDMA, and GSM. These technologies are not compatible to each other. That is, whenever a cellular phone user chooses one type of service (technology), it is hard for consumer to switch to another type of wireless service because of a lock-in cycle.

Hypothsis 2: *The advent of new wireless technology will reduce the market demand for old wireless technology under conditions of uncertainty.*

3.3 Data Collection

This study collects world wireless market data (i.e., the number of subscribes) for analyzing the evolution of wireless technologies. <Figure 1> plots the number of subscribers in each wireless technology from 1990 to 2006. The world wireless market experienced high growth from the mid-1990's until 2001. However, in 2002, the growth rate was not as strong, and expectations are that it will level off in the next few years, given the current technologies and the nearly saturated subscriber base. *GSM* will continue to be the dominant world technology, primarily because it is the only standard in Europe, the leading wireless market. *CDMA* has experienced high growth in the limited Asian market and will become the primary competition for *GSM* in the future. *TDMA*, a technology used mainly in the USA, will eventually become obsolete as providers upgrade to more advanced technologies, such as *GSM* or *CDMA*. Analog technology was completely phased out after 2004.

Based on 1985~2010 historical data and using *Loglet* software, <Table 1> shows the three important parameters; saturation, midpoint, and growth time. In the absence of data for WCDMA and cdma 2000 in 3G, the total market of 3G is estimated and then simply divided according to the current market share for CDMA and GSM because the 3G market will most likely evolve from GSM to



〈Figure 1〉 World Wireless Market

〈Table 1〉 Estimation of *Loglet* Parameters for each Technology

Technology	Saturation* (Millions)	Midpoint** (Year)	Growth Time*** (years)
Analog	50,700	1994	7.6
TDMA	52,300	1999	5.0
GSM	26,000	2001	7.1
CDMA	77,900	2001	4.7

Note) * Maximum value of this logistic and ratio to prior saturation (in parentheses).
** The point of inflection of the curve.
*** Time in which the logistic goes from 10% to 90% of its expected saturation level.

WCDMA and from CDMA to cdma 2000.

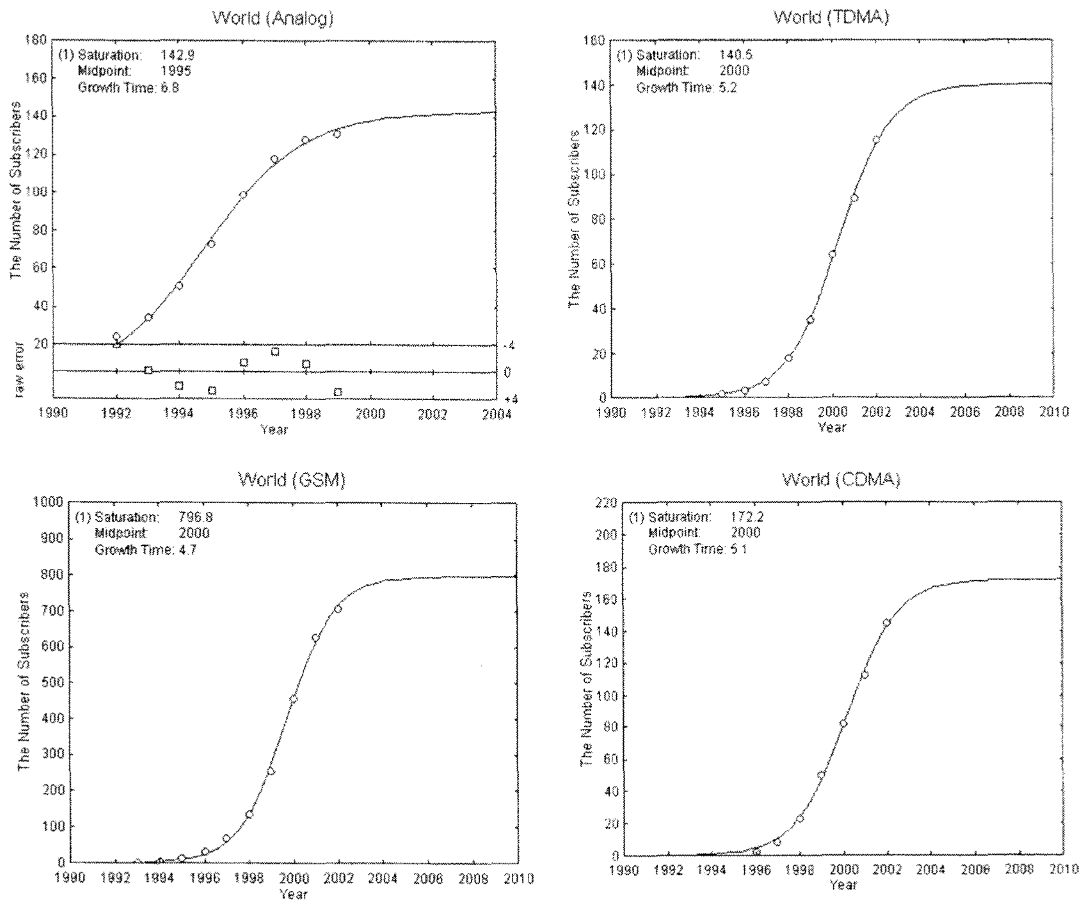
The first step for visualizing the impacts of new technologies is to estimate the growth rate, Äti, and the mid-point of saturation, t_{mi}, of each technology, based on actual historical data. Using these estimates, the market value line of each technology is drawn.

Ⅳ. Results Analysis

The wireless market is analyzed by indicating market size and market share of each technology, and by separating each technology's market share using the *Loglet Analysis* techniques.

Using world wireless market data, <Figure 2> shows each individual technology with a single logistic, with the parameter values estimated using the least squares algorithm. Despite the upward trend of the historical data, Analog technology is not a viable technology for the future. However, the *Loglet Analysis* is unable to draw a downward trend for an individual technology, like the declining Analog service.

Based on the result, hypothesis 1 is proved that the wireless technology follows a logistic curve in each technology.



〈Figure 2〉 Wireless Technologies

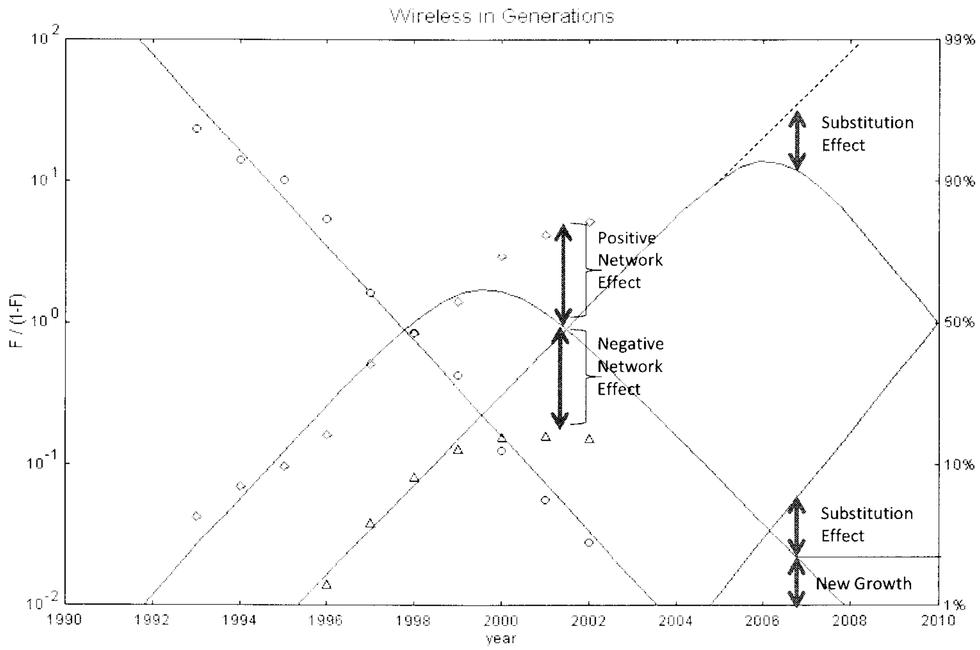
<Figure 2> shows the impact of competition among the various 2G technologies (i.e., GSM versus CDMA) and the substitution of 2G for 3G technology (i.e., WCDMA and cdma 2000) in the high-speed multimedia services market. Market share is based on the number of subscribers, and the substitution effect is felt immediately upon introduction of the new technologies. Projected growth rates and mid-point saturation values for the 3G technologies are based on the value estimations for GSM and CDMA technologies. In the base case, using a growth rate of 7% and a mid-point of saturation in 7 years, 3G technology realizes a 50% market share in 2010.

V. Conclusions

The paper presents the evolution of wireless technologies and analyzes the technological trajectory of wireless technologies using the *Loglet Analysis* tool. preliminary result shows that network effect (i.e., network externality) and substitution effect are shown and so it will be a main issue when network service providers introduce new services and technologies.

5.1 Contribution

This paper should provide strategic help to wireless service providers facing upgrades or migrations to the next generation by resolving the ambiguity of the nature of network evolution under competition. In summary, since the next generation wireless network technologies and architectures are still a subject of debate with no substantial implementation results, there is much work to do. With the further research, the scope of study can be expanded.



〈Figure 3〉 Wireless Technology Competition

5.2 Limitation of the Study

The paper is desirable to use all relevant data concerning technological development problems, but such data is generally unavailable in the market. So, the scope of this study is limited to only current market share data for the competing technologies in each generation. However, despite the data limitation, numerous experiments have been conducted by managing the model's parameters, and the results were used to explain current situations and give some clues to establish effective strategies. Although this study is purposely limited in scope, it can be expanded by considering other scenarios under different assumptions. The aim of this case study is to provide insight on the transition strategy of wireless service providers towards the next generation wireless network technologies.

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Abstract

The paper presents the technology trajectory of competitive wireless technologies in wireless industry. We attempt to trace the trajectory of wireless technologies with historical data, and then analyze its pattern. As a preliminary result, we find that there exists network effect and substitution effect in the trajectory. Our result can provide insight to wireless service providers where best to focus its efforts for maximizing overall gain in their networks as well as when to establish the transition strategy towards the next generation wireless network technologies.

Keywords: Competing Technologies, Technology Evolution, 3G, Network Effect, and Substitution Effect

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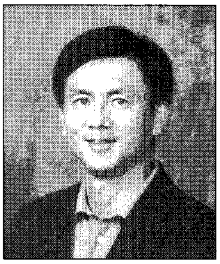

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현재 미국 뉴욕에 있는 호프스트라 대학교 부교수로 재직 중이며, 컴퓨터 및 네트워크 실험실 실장을 맡고 있습니다. 그는 피츠버그대학교에서 박사학위를 받았으며, 미국 콜로라도 대학에서 정보통신학 석사와 고려대학교에서 경영학 석사를 받았습니다. 학교경력 전에는 SK telecom에서 5년간 연구원으로 재직하였습니다. 연구분야는 전파식별(RFID)기술기반 기업정보시스템 개발, 온라인 소셜 네트워크 기술 설계 및 개발, 사이버공간에서의 보안 기술 정책 수립 등입니다.

본 논문은 지난 2011 한국경영정보학회 춘계학술대회에서 최우수논문상을 수상했으며 Information Systems Review 편집위원회에 의해 8월 12일 게재확정된 논문임을 알려드립니다.