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A Look into the Future of Wireless Mobile Communication Technologies

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A look into the future of wireless mobile communication technologies

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The number of wireless mobile communication service subscribers has reached 4.6 billion worldwide in 2009, and mobile revenues are expected to be over $1 trillion around 2012 according to the International Telecommunication Union (ITU) (ITU, 2010). A significant number of studies have been done to forecast the growing market and evaluate the new generation technology, the Beyond 3 Generation (B3G). However, there is no study forecasting when any of these new technologies will be commercialized. This paper presents a technical framework for forecasting the commercialization timeline of B3G technologies and provides insight on technology trajectories from 1G to 4G. The results show that a combination of technical parameters can explain heterogeneous wireless mobile communication technologies. Three parameters selected include channel bandwidth, channel bit rate, and data capacity for technical framework.

Keywords: Technology Forecasting, Wireless Mobile Communication Technologies, Multiple Regression Analysis

Introduction

Wireless mobile communication is one of the rapidly growing industries (Du Preez and Pistorius, 2003). Since the first mobile phone, Advanced Mobile Phone Service (AMPS), commercialized in Japan in 1979 (Smith and Collins, 2007), the number of subscribers worldwide exceeded 1 billion in 2002 (Minomo and Masamura, 2004). ITU(2010) forecasted it will grow to approximately 5 billion in 2010. OECD reports that the revenue in the worldwide mobile telecommunication market in 2007 was $493 billion (Figure 1).

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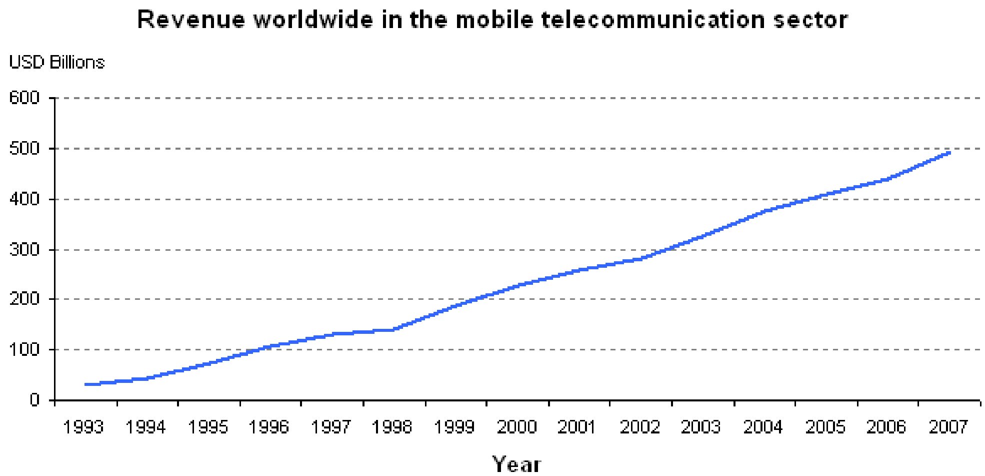

Figure 1 Revenue worldwide, Source: OECD Key ICT Indicators (OECD, 2009)

The third generation of wireless mobile communication started with CDMA2000 EV/DO in 2001. However, 3G licenses worldwide have been delayed due to the heavy investment requirements for new 3G infrastructure as well as lack of attractive applications (Ryu *et al.*, 2004; Park *et al.*, 2006). Wireless mobile telecommunication equipment and services can be rapidly developed, but developing infrastructure requires heavy investment and hence a long-range strategic plan over a timeframe of 10 years (Flament *et al.*, 1999). Technology forecasting helps to overcome the inherent uncertainty of research and development (R&D) activity in two ways: one is to set a R&D goal and the other is to identify opportunities by exploring technical characteristics in the future (Martino, 1993).

There is much related research on exploring technologies required for both 3G and beyond 3G. They can be grouped under three major streams:

1) Forecasting subscription and market growth with diffusion or extrapolation models (Kim *et al.*, 1999; Kumar *et al.*, 2002; Venkatesan and Kumar, 2002; Frank, 2004; Wenrong *et al.*, 2006; Yoo and Moon, 2006; Madden and Tan, 2007)

2) Foresight exercises with experts for development of a vision for the future of the wireless mobile communication technologies and related social needs. (Hanson and Ramani, 1988; Evci, 1994; Smyth *et al.*, 1995; Dasilva *et al.*, 1997; Mohr and Becher, 2000; Ohmori *et al.*, 2000; Bi and Zysman, 2001; Sun *et al.*, 2001; Gazis *et al.*, 2002; Evci *et al.*, 2003; Hu and Lu, 2003; Park *et al.*, 2006)

3) Scenario analysis on future wireless mobile communication technologies and their impacts on society (Flament *et al.*, 1999; Ryu *et al.*, 2004)

None of these studies attempted to forecast when and what kind of a future technology will be feasible with any quantitative forecasting method. Future trajectory of key technical parameters and performance of wireless mobile communication technologies can provide a window of feasible future technology and, therefore, help us to develop a more reliable and robust strategy. So, our major objective is to explore if we can come up with a framework to explain the evolution of wireless mobile communication technologies.

In order to answer this question, this paper utilizes the following steps: 1) define technology structure and parameters, 2) describe foreseeable technologies, 3) model the evolution of these technologies 4) forecast the expected year of commercialization of B3G technologies, and 5) provide and discuss a trajectory of future wireless mobile communication technologies.

Wireless Mobile Communication Technologies

In the early 1980s, the first generation (1G) of wireless mobile communication technologies included the Advanced Mobile Phone System (AMPS) introduced in the United States, Total Access Communication System (TACS) in the United Kindom, Nordic Mobile Telephone (NMT) system in the Scandinavian countires, C450 in Germany and Nippon Telephone & Telegraph (NTT) in Japan (Garg and Wilkes, 1996). These techologies used analog frequency modulation (FM) for speech transmission and frequency shift keying (FSK) for signaling (Padgett *et al.*, 1995). The critical problems of the first generation (1G) included capacity bottlenecks and incompatible standards.

Therefore, the second generation was developed to provide higher capacity and a continental system with full international roaming and handoff (Goodman, 1991). This generation, including Global System for Mobile Communications (GSM), IS-136 (time-division multiple access, TDMA), IS-95 (code-division multiple access, CDMA), and Personal Digital Cellular (PDC), significantly reduced the cost of handset and supporting infrastructure systems (Bi and Zysman, 2001). The second and a half generation (2.5G) is the interim platform to bridge the 2G systems into the 3G by bringing the internet into wireless mobile communication (Sun *et al.*, 2001). WiDEN, GPRS and EDGE are systems in this generation. However, these techologies are still optimized for voice service, and not for proper data communication (Smith and Collins, 2007).

The third generation (3G) now is being deployed and it improves the spectral efficiency, cost of the system, and data/multimeida capacity (Bi and Zysman, 2001). CDMA2000 EV/DO, WCDMA (UMTS), TD-CDMA, and TD-SCDMA are technology platforms developed for 3G. Througout three generations, wireless mobile communication operators have been selecting and investing in a path to transition into 3G (Smith and Collins, 2007). Wireless mobile communication technologies ranging from 1G to 3G are summarized in Table 1.

Table 1 1G, 2G, 2.5G, and 3G technologies

Generation	1G	2G	2.5G and 2.7G	3G
Systems	NTT, NMT-450, NMT-900, C450, AMPS, TACS, NAMPS	CT2, IS-54, PDC, CDMA one, GSM 900, JDC, GSM1800, iDEN	WiDEN, HSCSD, cdma2000, GPRS, EDGE	WCDMA (UMTS), TD-CDMA, TD-SCDMA, CDMA2000 DO/EV, HSDPA
Year of first adoption	1979 (NTT)	1990 (D-AMPS)	2001 (cdma2000)	2002 (CDMA2000 EV/DO)
Country of first adoption	Japan	U.S.	Korea	Korea
Technical Issues	Introducing cellular approach (frequency reuse, handoff, central control)	Increasing system capacity up to 3 times over 1G, improving security	Utilizing existing infrastructure, introducing packet data service	Improve spectra efficiency by using smaller cells, providing high quality, multimedia service and global standard
Service	Voice, Mono-service	Voice, SMS, Mono-media	Data service	Voice, Data, Multimedia

Source: Garg and Wilkes (1996), Gibson(1996), Sun (2001) and Gruber (2005)

The third generation systems may not be sufficient to fulfill the explosively increasing traffic in 2010. The fourth generation will be required to cover at least 10 times the capacity available in 3G (Ohmori *et al.*, 2000). Numerous research studies provide a vision for expected technical capacity of the Beyond 3 Generation (3G) or the fourth generation (Ohmori *et al.*, 2000; Jorguseski *et al.*, 2001; Sun *et al.*, 2001; Evci *et al.*, 2003; Hu and Lu, 2003; Ryu *et al.*, 2004; Seungwan *et al.*, 2005; Dongchun *et al.*, 2006). ITU-R, a standards body subcommittee of the International Telecommunication Union (ITU) relating to radio communication, proposed a concept for the Beyond 3rd Generation: a high data rate, a low cost, use of IPv6, portability of numbers, and integration of wired and wireless communications (Ryu *et al.*, 2004).

Table 2 4G Visions Summary (modified from Sun *et al.*, 2001)

Property	4G
Starting time	2010-2012
Driven technique	Intelligent software, Auto configuration
Representative standard	OFDM, UWB
Radio frequency	3GHz – 5GHz
Data capacity	10Mbps – 20Mbps
Multi-access technologies	FDMA, TDMA, CDMA
Service type	Multimedia, Machine to Machine

Research Framework

This section will describe the technology framework used to characterize the wireless technologies. Data collection and analysis methods will also be described.

The four technical parameters defined in the technology framework section have trade-offs among them. More channel bandwidth allows a system to produce more throughputs such as data capacity while reducing the number of channels within the allocated spectrum. The reduced channels, hence, reduce the overall number of calls available. The long-term trend is to increase data capacity by compensating the number of channels. Therefore, technology has been developed to improve the efficiency so that more users can have access to more data in a given spectrum allocation.

A composite measure of a technology is required if there are possibility of trade-offs among technical parameters (Martino, 1993). A designer will decide which parameters should be emphasized and which will be sacrificed for a specific application of a technology or device. Therefore, several devices or technologies in the same generation may have different values for the various parameters. Wireless communication technologies are characterized as heterogeneous for this reason.

Alexander and Nelson (1973) defined a composite measures of technical parameters as “technology frontier” in the N-dimensional space. They illustrated that a designer has a freedom to move in that plane which represents the current state of the art by trading an increase in one parameter for a decrease in others. Multiple linear regression is used to find this plane (Martino, 1993).

The planar technology frontier approach with multiple linear regression is a reasonable tool to develop a long-term forecast for the performance of a technology or a device (Martino, 1993). This approach is used in this study to represent state of the art and heterogeneous characteristics of wireless mobile communication technologies with possible trade-off relationships among technical parameters. Another reason for using this approach instead of growth curves such as Fisher-Pry is that the technical upper limit of wireless communication - data capacity - is not known at this time.

Recent mobile phones include various services which were not available in the past generations such as email, World Wide Web, music or movies. Lee (2006) defined four categories to evaluate performance of wireless mobile communication technologies such as voice quality, data quality, picture/vision quality and service quality. Voice quality is generally measured subjectively. Three metrics, Circuit Merits (CM), Mean Opinion Score (MOS) and Diagnostic Rhyme Test (DRT), are used to measure voice quality. Data quality can be measured by bit error rate, chip error rate, symbol error rate, and frame error rate. Picture/vision quality can be understood by six metrics such as color acuity, depth perception, flicker perception, motion perception, noise perception, and visual acuity. Finally, service quality consists of three factors: coverage, required grade of service, and number of dropped calls. This factor has a trade-off with respect to the transmission power and cost. These performance factors help us to evaluate overall performance of wireless mobile communication technologies. Recent research (Ryu *et al.*, 2004) exploring wireless mobile communication technologies used similar factors.

While these functional metrics can help us to evaluate the technologies, they are limited in assessing future feasibility. Generally, technology forecasts using these functional parameters or performance measures are more proper for the purpose of market planning while technological parameters are more appropriate for a forecast when R&D planning is required (Martino, 1993).

A technological framework for wireless mobile communication technologies including key technological parameters can help us to forecast feasibility of B3G technologies. The current wireless radio communication systems consist of several kinds of wireless devices such as simple cordless phones, mobile cellular systems and personal communication systems. These different radio communication systems share some common characteristics. The fundamental objective of wireless communication systems is to provide communication channels between a mobile radio station and a radio port or base station which connects users to the fixed network infrastructure through the electromagnetic waves. Therefore, one important goal of mobile radio technology is to provide basic telephone service to more users with limited electromagnetic waves (Goodman, 1991) .

The major design factors can be capacity, cost of implementation, and quality of service (Gibson, 1996). The capacity of wireless systems is closely related to frequency usage. The frequency spectrum on which wireless communication equipment depends is a limited natural resource. A major problem of the radio communication system is the limited availability of radio-frequency spectrum due to high demand. Therefore, the ideal mobile system can be defined by a system operating within a limited assigned frequency band and serving almost unlimited number of users (Lee, 2006).

The higher capacity can be achieved through advanced transmission techniques with efficient speech coding, error correcting channel codes, and bandwidth efficient modulation (Goodman, 1991). Key technology parameters regarding this capacity include the channel bandwidth, information compression, variable bit-rate control, improved channel assignment algorithms, and selection of multiple access schemes (Garg and Garg, 2001). These five factors should be considered in a forecasting model directly or indirectly.

The most common composite measure of the capacity is spectral efficiency. A good measure of spectral efficiency helps one to estimate the capacity of a mobile communications system and allows one to set up a minimum standard as a measure of reference (Garg and Garg, 2001). Therefore, the metrics used to measure spectral efficiency can also provide performance features of a wireless mobile communication technology, and hence good technical parameters for our forecasting model. Spectral efficiency can be defined as follows (Garg and Wilkes, 1996):

$$\text{Spectral Efficiency (Erlangs/MHz/km}^2\text{)} = \frac{\text{Total number of channels available in the system}}{(\text{Bandwidth})(\text{Total coverage area})}$$

Number of channels and channel bandwidth are also important technical parameters for wireless communication technologies. The total coverage area is excluded in this study because this factor is difficult to measure consistently across generations and is frequently specific to the particular implementation of carriers. In addition, other important technical parameters, channel bit rate, and data capacity, are considered in the model as they are important design parameters measuring performance of wireless communication technology which are not explicitly included in the spectral efficiency formula.

Table 3 Definition of key technical parameters identified

Parameter	Definition	Metrics
Channel bandwidth	Channel bandwidth, channel spacing, RF channel spacing or bandwidth per channel is size of radio frequency per each channel.	kHz
Number of channels	Number of channels is the number of pairs of radio frequencies meaning a communications path between two computers or devices.	Number
Channel bit rate	The channel bit rate is the channel transmission bit rate for digitally modulating the carrier and is also called the "transmission rate" or "symbol rate/chip rate". This is the maximum theoretical digital bit rate that can be produced through the network medium by the utilized technology.	kbps
Data capacity	Data capacity is the actual throughput bit rate for the data (payload) that is being passed through the system.	kbps

Throughout the study a panel of experts in the wireless industry was consulted. The panel members were technical experts from US and Korean institutes. They have confirmed the four technical parameters are important in the design of wireless communication technologies.

The detailed definitions of four parameters which are identified in this study are provided in Table 3. These parameters will be discussed along with their trends and trade-offs relation, and some of them will be selected for the forecasting model at the following section.

The multicollinearity is critical issue especially when regression is used to understand relation among independent variables and impact of each independent variable to the dependent variable. However, the use of regression for forecasting has typically been considered to be relatively robust to these problems when the some tradeoffs are expected to continue as in the past (Farrar and Glauber, 1967; Belsley, 1982; Belsley, 1987).

Since the purpose of this study is to forecast year of the first commercialization of B3G mobile communication technologies but not to investigate the relationships among independent variables nor degree of influences of them to dependent variable, the emphasis is on how well the model forecast when new technologies will be commercialized. However, basic test for possible multicollinearity should be done to check if it harms structural estimation for the estimated period. In this study, three indicators are used to check multicollinearity; VIF, Condition Index, and “perverse sign” of coefficients. If VIF is more than 10 or Condition Index more than 30, collinearity exists.

Channel Bandwidth and Number of Channels are expected to have strong linear relationship as technically number of channels is calculated by channel bandwidth and total bandwidth used by a technology and cause collinearity. The result of collinearity diagnostics also shows that Number of Channels causes collinearity and harm regression structure. Therefore, Number of Channels is excluded from the forecasting model in order to avoid violation of the assumptions of linear regression. The detail result of collineairty diagnostics is discussed at the analysis section.

This study suggests that four technical parameters are important to understand the state of the art of wireless communication technologies. However, if any technical parameter causes collinearity and harm regression structure, the forecasting based on the model could be wrong. Therefore, we examine collinearity by three indicators, VIF, Condition Index, and perverse sign of coefficients. The result is summarized in Table 4.

Table 4 Result of collinearity diagnostics

Criteria	3G Forecasting Model		B3G Forecasting Model	
	4 variables (CBR, NOC, CBR, DCP)	3 variables (CBR, CBR, DCP)	4 variables (CBR, NOC, CBR, DCP)	3 variables (CBR, CBR, DCP)
VIF	All less than 10	All less than 10	13 (CBW), 11 (CBR)	All less than 10
Condition Index	36 (5^{th} Dimension)	All less than 30	36 (5^{th} Dimension)	All less than 30
Perverse Sign	Yes (CBW)	No Perverse Sign	Yes (CBW)	No Perverse Sign
Result	Collinearity	No Collinearity	Collinearity	No Collinearity

Number of Channels is expected to cause collinearity because of its inherent relation with Channel Bandwidth. The result consists with the expectation. The Condition Index of multi-regression model with four variables presents that the collinearity exists. The perverse sign of the coefficient of Channel Bandwidth indicates the collinearity harm the regression structure. Also, the same problem is found at the B3G model with four variables. If the variable, Number of

Channels, is excluded, the two multi-regression models doesn't have any problem caused by collinearity.

Therefore, the model for forecasting wireless mobile communication technologies using a composite measure is defined as following with three variables;

$$Y = b_1 \times X_{CBW} + b_2 \times X_{CBR} + b_3 \times X_{\mathrm{DCP}} + b_0$$

Y : The year of first commercialization of a wireless communication technology

X_{CBW} : Channel bandwidth

X_{CBR} : Channel bit rate

X_{DCP} : Data capacity

b_1 : Regression coefficient of channel bandwidth

b_2 : Regression coefficient of channel bit rate

b_3 : Regression coefficient of data capacity

b_0 : Constant

Using multiple linear regression for forecasting has a long history (Merz *et al.*, 1972; Alexander and Nelson, 1973; Rohatgi and Weiss, 1977; Hutzler *et al.*, 1985) and raises obvious questions about multicollinearity (Farrar and Glauber, 1967; Fujii and Mak, 1981; Askin, 1982; Belsley, 1982; Belsley, 1984; Belsley, 1987). The potential for tradeoffs among independent variables is a violation of the independences assumption among independent variables when regression method is used.

Data for the three parameters and year of first commercialization of 21 wireless mobile communication technologies from 1G to 3G were gathered from secondary data sources (Garg and Wilkes, 1996; Gibson, 1996; Lee, 2006; Smith and Collins, 2007). Since some sources use different metrics and concepts for the parameters, Validation was done by comparing the information with multiple sources and through informal interviews with members of our expert panel. The final data set used in this study is provided at the Table 5.

Table 5 Data used for the forecasting model

Technology		Generation	Year of the first Adoption	Channel Bandwidth (CBW, kHz)	Channel Bit Rate (CBR, kbps)	Data Capacity (DCP, kbps)
NTT	Nippon Telegraph & Telephone	1G	1979	25	0.3	0.3
NMT-450	Nordic Mobile Telephone 450	1G	1981	25	1.2	1.2
AMPS	Advanced Mobile Phone Service	1G	1983	30	10.0	10.0
C-Netz	The Radio Telephone Network C utilizing C450 standard	1G	1985	20	5.3	5.3
TACS	Total Access Communications System	1G	1985	25	8.0	8.0
NMT-900	Nordic Mobile Telephone 900	1G	1986	12.5	1.2	1.2
D-AMPS	Digital AMPS (D-AMPS, IS-54, or TDMA)	2G	1990	30	48.6	9.6
GSM 900	Global System for Mobile communications with 900 MHz	2G	1990	200	270.8	14.4
CT2	A digital FDMA system that uses Time Division Duplexing technology	2G	1991	100	72.0	19.2
CDMA One	Code Division Multiple Access (CDMA One or IS-95)	2G	1993	1250	1228.8	14.4
JDC	Japanese Digital Cellular System	2G	1993	25	42.0	14.0
GSM1800	Digital Cellular System 1800	2G	1993	200	270.8	9.6
iDEN	Integrated Digital Enhanced Network	2G	1994	25	64.0	9.6
cdma2000	CVDMA2000 1XRTT	2.5G	2001	1250	1228.8	153.0
GPRS	General Packet Radio Service	2.5G	2001	200	270.8	128.0
EDGE	Enhanced Data rates for GSM Evolution	2.7G	2002	200	812.5	384.0
CDMA EV/DO	CDMA 2000 Evolution-Data Optimized or Evolution-Data only	3G	2002	1250	1228.8	384.0
WCDMA	Wideband Code Division Multiple Access	3G	2004	5000	5760.0	384.0
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access	3G	2006	1600	3300.0	384.0
TD-CDMA	The primary air interface used by UMTS-TDD	3G	2006	5000	3300.0	384.0
HSDPA	High-Speed Downlink Packet Access	3G	2006	5000	960.0	14400.0

The data of 21 technologies are divided into two sections to validate the forecasting model. The first part consists of 1G to 2.7G. The second part of 3G will be used to evaluate if the forecasting model based on the first data set is valid. Then, the whole 21 data set will be used to build the forecasting model for B3G wireless technologies.

Results

Each trend of the three technical parameters of 21 technologies is examined using simple regression. The original data and logarithmically transformed data are compared to find which one is proper for the multi-regression model in the Table 6. The result shows that log-transformed data of all three variables have better R^2 and p-values. This supports that each technical parameter is growing exponentially rather than linearly. Therefore, logarithmically transformed data of three variables are used for the forecasting model.

Table 6 Linear and exponential regression models

variable	Original data		Logarithm transformed data	
	R^2	p-value	R^2	p-value
X_{CBW}	0.472	0.001	0.723	0.000
X_{CBR}	0.446	0.001	0.839	0.000
X_{DCP}	0.128	0.112	0.849	0.000

Validation: Forecasting 3G technologies

Table 7 presents the results of the multi-regression analysis of the proposed model with three variables. The first data set of sixteen technologies from 1G to 2.7G is used.

Table 7 The result of multi-regression for the 3G forecasting model

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1982.094	2.946		672.801	.000
	LNCBW	-.338	1.026	-.070	-.329	.748
	LNCBR	1.230	.870	.454	1.413	.183
	LNDCP	2.169	.873	.560	2.484	.029

a. Dependent Variable: YEAR

The following forecasting model is used to fit to the second data set of 3G wireless mobile communication technologies and validate the extrapolation method. R-square of this model is 0.857 and p-value is 0.000. Therefore, this model can explain 86% of the 16 technologies with three technical parameters.

$$Y = -0.338 \times X_{LNCBW} + 1.23 \times X_{LNCBR} + 2.169 \times X_{LNDCP} + 1982.094$$

Y : The year of first commercialization of a technology

X_{LNCBW} : Log transformed channel bandwidth

X_{LNCBR} : Log transformed channel bit rate

X_{LNDCP} : Log transformed data capacity

The actual year of commercialization and forecasted year of wireless mobile communication technologies from 1G to 2.7G were compared. Figure 2 graphically shows how forecasted years are close to the actual year of commercialization during the period from 1979 to 2002. The x-axis and y-axis plot actual year and forecasted year of commercialization of a technology respectively. The ideal forecasting model will arrange all technologies along with the diagonal line. The technologies plotted above the line means that they are launched in the market earlier than the model forecasted. The graph also shows that while the 1G and 2G technologies are scattered on the line, all 2.5 and 2.7G technologies are located below the line. This implies that these technologies (2.5 and 2.7G) are commercialized late comparing the overall trend of the technological trajectory.

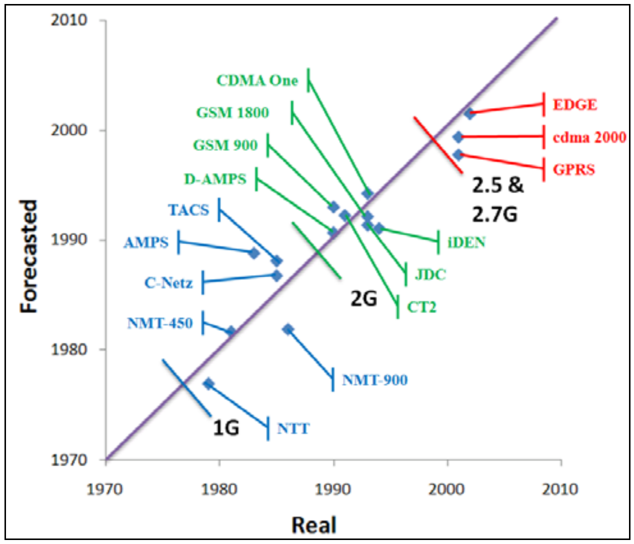

Figure 2 Comparing the real and forecasted year of wireless mobile communication technologies from 1G to 2.7G

Then, the model is used to forecast 3G technologies which already have been commercialized. The forecasted year of 3G technologies and actual year of the first adoption are compared in the Figure 3. All 3G technologies except for HSDPA are located below the line which means that they took longer time until they were launched considering the trend of commercialization of technologies from 1G to 2.7G.

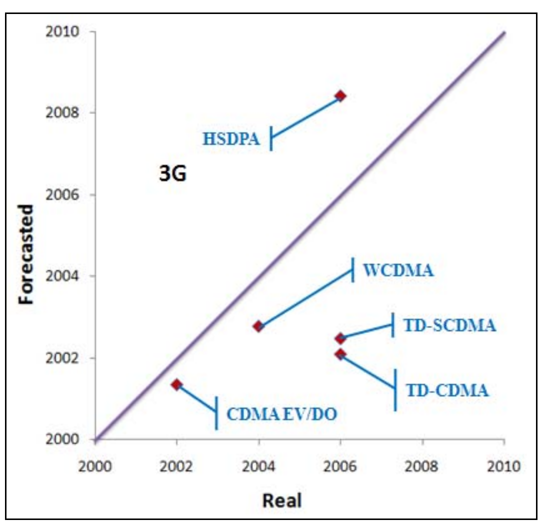

Figure 3 Comparing the real and forecasted year of 3G wireless mobile communication technologies

In Figure 3, TD-SCDMA and TD-CDMA show a relatively large gap between the forecasted and real year of the first commercialization. This comes from a unique situation regarding why these technologies had been developed. TD-SCDMA and TD-CDMA were developed by the Chinese Wireless Technology Standard Group to protect and improve the national technological competency and market and late entrants in the market (Edwards, 2003; Zheng *et al.*, 2005). The Table 8 summarized the result.

Table 8 Forecasted year of 3G technologies

3G Technologies	Actual Year	Forecasted Year
CDMA EV/DO	2002	2001
WCDMA	2004	2003
TD-SCDMA	2006	2003
TD-CDMA	2006	2002
HSDPA	2006	2008

The Mean Absolute Error (MAE) of the result is 2.2 years. If two Chinese technologies are excluded, the MAE is 1.3 year. A statistic test is used to validate further whether the forecasting model is appropriate for the estimation of the year of first commercialization of five 3G technologies. Since the number of data is less than thirty and doesn't follow a normal distribution, the Wilcoxon Signed-Rank test is used. The result provided in the Table 9 shows that there is not a statistically significant difference between the actual and predicted years. Therefore, it can be concluded that the forecasting model using multi-regression is statistically significant and can be used to forecast the next generation of wireless mobile communication technologies (4G.). However further technology development may alter this model. Periodic review of what the model predicts in the future would help to validate the model.

Table 9 Result of Wilcoxon Signed-Rank test of real and forecasted years of 3G technologies

	Forecasted Year - Real Year
Z	-1,225[a]
Asymp. Sig. (2-tailed)	,221

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Forecasting B3G Technologies

The whole data sets from 1G to 3G of 21 wireless mobile communication technologies are used to build the forecasting model for B3G technologies. The regression results with the three parameters are provided in Table 10. R-square of this model is 0.915 and P-value is 0.000.

Table 10 Result of regression with three variables to forecast B3G

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1981,180	1,894		1046,114	,000
	LNCBW	-,114	,681	-,027	-,167	,869
	LNCBR	1,515	,510	,498	2,973	,009
	LNDCP	1,808	,486	,523	3,720	,002

a. Dependent Variable: YEAR

Finally, the forecasting model for a B3G wireless mobile communication technology is proposed as follows.

$$Y = -0.114 \times X_{LNCBW} + 1.515 \times X_{LNCBR} + 1.808 \times X_{LNDCP} + 1981.180$$

The regression coefficient data capacity has the highest value and statistically significant. This implies that data capacity has higher influence to the technological change. Wireless mobile communication technologies have been developed in a way to provide various multimedia services to more people given a constant broadband. Therefore, data capacity could be considered as the most important indicator of technical improvement (Hata, 1999; Sun *et al.*, 2001; Hu and Lu, 2003; Ryu *et al.*, 2004).

The coefficient of Chanel Bandwidth has a negative sign in both 3G and B3G forecasting models. This is consistent with the technical characteristic of Channel Bandwidth. This could be considered as input of two throughput variables, Channel Bitrate and Data Capacity. Given same channel bitrate and data capacity, a more developed technology would use less bandwidth. Therefore, the coefficient of this variable can be negative.

Case of Forecasting 4th Generation (4G) Technologies

An example is provided below to demonstrate how the forecasting model can be used to overlook the features of the future technologies. Since there is not a specification for 4G technologies available yet, a possible 4G technology is defined based on the available literature (Table 11) at the Table 12.

Table 11 Suggested specification of 4G

	Sun *et al.* (2001)	Ryu *et al.* (2005)	Hu and Lu (2003)
Starting year	2010-2012	2005 (test)	2005-2020
Spectrum	3GHz - 5GHz	3GHz - 5GHz	2GH-5GHz
Bandwidth	10MHz – 20MHz	5MHz – 20MHz	-
Transmission rate	-	100Mbps	100Mbps
Multiplexing	FDMA, TDMA, CDMA	OFDM-FDMA, FDD, frequency-hopping	OFDM, HDR
Driven Technology	Intelligent software, Auto configuration		Open wireless architecture, AMC

Table 12 Specifications of the Virtual 4G used for forecasting

	Year of first commercialization	Channel Bandwidth (CBW)	Channel Bitrate (CBR)	Data Capacity (DCP)
4G (virtual)	Unknown	20 MHZ[1]	10Mbps[2]	100Mbps[3]

1. Channel Bandwidth of 20MHZ is used as suggested by Sun *et al.* (2001) and Ryu *et al.* (2005)

2. Number of Channels and Channel Bitrate are assumed based on the previous technologies.

3. Data Capacity of 100Mbps is used as suggested by Ryu *et al.* (2005) and Hu and Lu (2003).

The forecasted year of the first commercialization of the target technology

$= -0.11 \times 9.90 + 1.52 \times 9.21 + 1.81 \times 11.51 + 1981.18$

= 2015

According to the forecasting model, the virtual 4G technology which can fully support data capacity of 100Mbps is expected to be commercially available in 2015. The result is closer to the year foresighted by Hu and Lu (2003).

Wireless carriers may deploy various technologies with lower data capacity than full 4G technology until market growth and infrastructure for the new generation are ready. Therefore, a sensitivity analysis using different performance scenarios on each parameter can provide better insight into the possible future of wireless technologies. Figure 4 shows how the time to market of 4G changes along with the data capacity used in the forecasting model. If 4G with the data capacity of 20Mbs is launched, the model forecasts that it will be commercialized in 2012. Therefore, depending on the actual data capacity of 4G, launching time of the technology could range from 2012 to 2015.

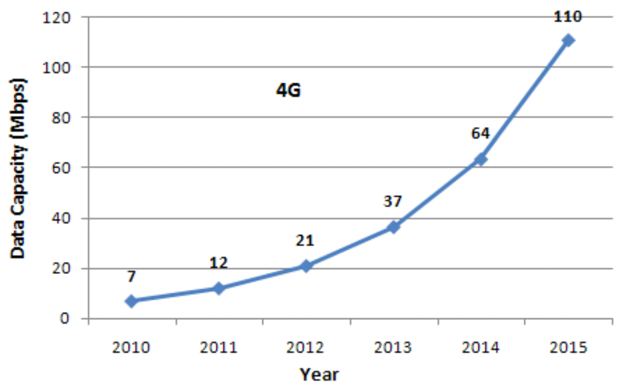

Figure 4 Sensitivity analysis with different data capacity (DCP)

Before the second generation was fully serviced, the migration technologies called 2.5G and 2.7G had been deployed. The migration stage of wireless mobile communication technologies provides benefits of extending the previous infrastructure and fast adoption of a new generation. The sensitivity analysis shows when 3.5G (migration between 3G and 4G) and 4G technologies will be available in the market in Table 13.

Table 13 Forecasting result of 4G

Technology	Channel Bandwidth (CBW, MHz)	Channel bit rate (CBR, Mbps)	Data Capacity (DCP, Mbps)	Forecasted Year
Migration (3.5G)	20	5	10	2010
	20	5	30	2012
	20	5	50	2013
4G	20	10	20	2012
	20	10	100	2015

All technological trajectories from 1G to 4G are illustrated in Figure 5. Two interesting facts are found in the trajectories. A new generation was introduced in the market every 11 years later after the first introduction of previous technology generation, and this is expected to continue at the 4th Generation. In other words, each generation from 1G to 3G has been used 11 years until a new generation. However, the time-lag between two generations has been increased by three years. The gap between 1G and 2G is 4 years, and 2G and 2.5G which is migration for 3G 7 years. The model forecasted that 4G will be introduced 10 years later after the last technology of 3G. This may happen because of technical difficulty to develop further generation and effort for standardization.

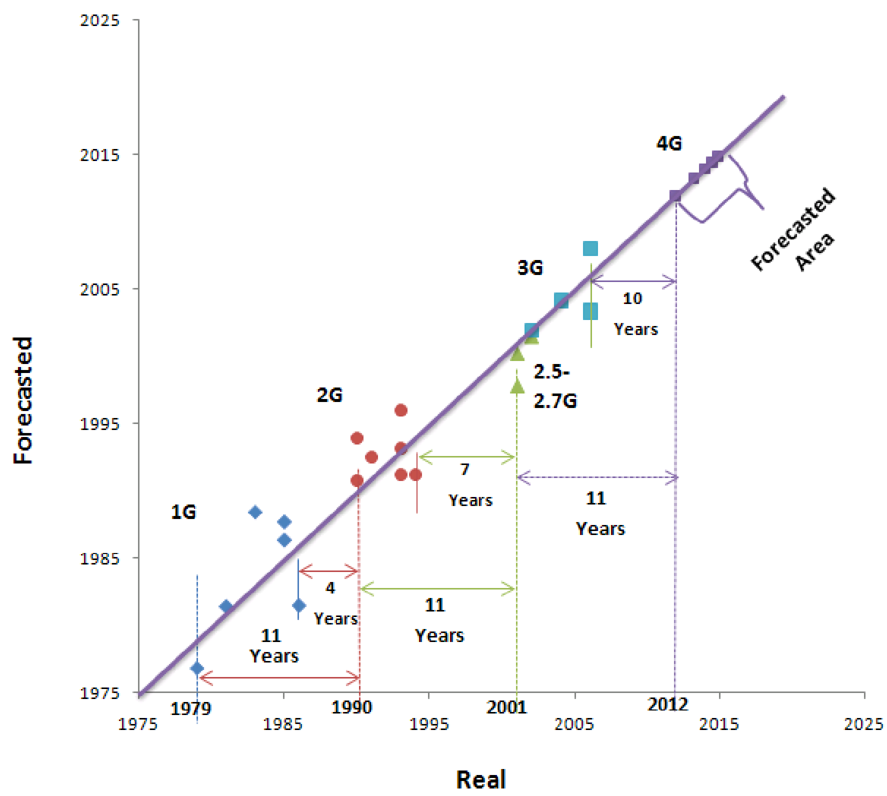

Figure 5 Technology trajectories from 1G to 4G

This result is consistent with the technological trends of wireless communications and the market needs. Since the first wireless phone introduced in the market, various technologies and standards competed in the second generation of wireless technologies. However, as customers' needs for seamless connection and ubiquitous communication worldwide increased, standardization and convergence of multiple technologies became critical in developing next generation technologies. Therefore, it is expected that only a few 4G technologies will be developed.

Two interesting facts were found from the technology trajectories. A new generation including migration stage of wireless mobile communication technology had been established in the market in every 11 years. Another finding was the increasing time-lag between the end of the old generation and the beginning of the new generation. Digital AMPS (D-AMPS), the first 2G technology, was commercialized four years later after the last 1G technology, Nordic Mobile Telephone 900 (NMT-900), was introduced in 1986. The migration generation of the third technologies (2.5G), cdma2000 and GPRS, took seven years to reach to the market after the last 2G technology. The model forecasted this trend will be continued at 4G.

Conclusions

The wireless communication market has been skyrocketing for 25 years since its first introduction, and as a result wireless communication technology is one of the fast innovating technologies. This study provides a better understanding of both those technologies and markets by reviewing past and current technologies and predicting future technologies. For this purpose, five steps of forecasting B3G technologies are suggested as followings.

Step 1: define technology structure and parameters

A technology structure and a forecasting model for the fourth generation wireless mobile communication technology (4G) with three technical parameters -- channel bandwidth, channel bit rate, and data capacity -- are introduced.

Step 2: describe foreseeable technologies

The twenty one wireless technologies from 1G to 3G which has been commercialized are identified with their technical specifications. Also, possible features of the 4^{th} Generation wireless technology are suggested based on literature review. The data capacity of the technology is expected to reach 100 Mbps.

Step 3: model the evolution of technologies

Extrapolation method was used with the past data of 21 wireless technologies from 1G to 3G to build the forecasting model. The collinearity diagnostics was performed to check if there was any technical parameter caused collinearity and harm regression structure. Three criteria, VIF, Condition Index, and perverse sign, are used for this purpose.

Step 4: forecast the expected year of commercialization of B3G technologies

The model forecasted that the 4G technology supporting 100Mbps transmission will be commercialized in 2015. In addition to the forecast of the target technology, further sensitivity analysis was performed to understand when the first migration will be deployed and how the evolution of 4G technology will be proceeding in the future.

Step 5: provide and discuss a trajectory of future wireless mobile communication technologies

The trajectory of 26 technologies including 5 expected B3G technologies was suggested by the forecasting model. The trajectory showed that the next generation had been launched in 11 years after the first introduction of the previous generation throughout all generations. The fourth generation technology is also expected to be commercialized in 11 years after the first migration technology of 3G, cdma2000 and GPRS in 2001.

There are also some limitations in this study. The model was built on three technical factors. Therefore, the forecasting result is vulnerable to the selection process for these factors. They were selected based on literature review and experts' opinion in this study. Patent or bibliometric analysis could be considered to make the forecasting model more robust.

Forecasting accuracy is dependent on how well the underlying assumption of a certain method is fit to the real data and model (Levary and Han, 1995). Trend extrapolation method was used to forecast wireless mobile communication technologies because the limit of the current technical approach was not well defined, the performance and operation of B3G were unknown, and a long-term forecast was required. The model assumes that performance of 4G technologies will increase exponentially. The model showed that the current and previous generations fit well to the exponential trend, but if 4G technologies do not follow this trend, the overall forecasting model will need to be modified with new data.

The study focused only on technical factors to forecast the future of wireless mobile communication technologies without detailed consideration of the markets, so the year of first commercialization was used to reflect market adoption indirectly into the model. However, market penetration and carrier's strategy for both current and future wireless mobile communication technologies need to be incorporated into the analysis in order to provide more comprehensive and accurate forecasting. Even though there are some limitations, this study provides a useful forecasting framework and an outlook for future wireless mobile communication technologies through a quantitative analysis.

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