8-2012

Forecast of Wireless Communication Technology: A Comparative Study of Regression and TFDEA Model

Dong-Joon Lim
Portland State University

Timothy R. Anderson
Portland State University, tim.anderson@pdx.edu

Jisun Kim
Portland State University, jisunk@pdx.edu

Citation Details

Lim, D., Anderson, T. and Kim, J. (2012) Forecast of Wireless Communication Technology: A Comparative Study of Regression and TFDEA Model. In PICMET '12: Technology Management for Emerging Technologies. http://archives.pdx.edu/ds/psu/9650

2012 Proceedings of PICMET '12: Technology Management for Emerging Technologies.

Forecast of Wireless Communication Technology: A Comparative Study of Regression and TFDEA Model

Dong-Joon Lim, Timothy R. Anderson, Jisun Kim
Dept. of Engineering and Technology Management, Portland State University, Portland - USA

Abstract--**This study presents a formal comparison of TFDEA with regression model to forecast wireless communication technology. In addition to the data set from the former research, up-to-2011 4G network technologies are added and analyzed. The research was designed to set the point of forecasting in 2001 so that technologies between 2001 and 2011 are to be forecasted using data set between 1979 and 2001. The results from both TFDEA and regression model are compared and discussed. This comparative study can provide forecasters with different aspects between 'best-practice measurement' and 'average practice measurement' and, ultimately, help to select the suitable approach for their purposes.**

I. INTRODUCTION

Since the first introduction in *PICMET '01* [1], technology forecasting using data envelopment analysis (TFDEA) has been applied to various areas and proved the usefulness associated with its inherent characteristics of taking advantage of disruptive technologies [2][3].

This study is a follow-up research of a paper that applied TFDEA to mobile wireless communication technologies in 2008 [4]. The original paper examined state-of-the-art (SOA) wireless technologies up to 2001 which could cover the early-third generation (3G.) Specifically, former research divided the data set into two parts with a fixed point in time thereby making the earlier, up-to-1996, part of the data set as a 'progress learning period' and later, post-1996, part of the data set as a 'historical future period' in order to demonstrate the accuracy of the model. However, even though this backtesting was successful to forecast future technology beyond the data set, it couldn't prove the real worth of TFDEA due to several retrogressed 3G wireless technologies in terms of spectral efficiency.

This paper extends the data set up to current 4G mobile wireless communication technologies and contrasts the forecast result from TFDEA with regression model. For objective comparison, same backtesting approach is taken with a fixed point in time of 2001 so that up-to-2001 technologies have been learned and post-2001 technologies are validated according to each method. The result not only suggests which method should have been used by the technology forecaster in 2001 but would give credibility to each method for a better forecast today.

II. BACKGROUND

Compared to the other industries, technology forecasting in the field of wireless communication has two significant implications: one is a large scale investment planning and the other is as a role of basic technology.

First of all, 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 [5]. From the Deloitte technical report, U.S. investment in 4G networks would fall in the range of $25 to $53 billion during 2012 to 2016 in accordance with various scenarios of the next standard technologies [6]. This large range of estimation implies how much this industry is sensitive to the deployment pace of the next generation technologies. Besides, with regard to intellectual property (IP) issues, forecasting specifications of future wireless technologies can provide corporate level decision makers with valuable information [7].

The latter issue of basic technology is well represented by the term 'Wireless Ecosystem [8].' Within this virtuous cycle, investment in, and deployment of, new spectrum spurs the roll-out of new services, these services fuel the construction of advanced networks, advanced networks stimulate the development of innovative devices and operating systems featuring new capabilities, new devices and operating systems spur the creation of novel applications and content, and applications and content result in increased consumer demand and adoption. In other words, there are a number of stakeholders who can benefit from the future standard of wireless technology as a today's basic industry [9]. For example, experts are expecting that the cloud computing industry will enter a new phase with next generation wireless technology [6]. Therefore, it is crucial for people in this wireless ecosystem to make correct and timely decisions based on properly forecasted future.

III. DATASET

Four technologies; HSDPA, WiMAX, LTE and HSPA+, which can cover up to current 4G technologies, have been added to the former data set (see Table 1.) Two parameters; bandwidth and bitrate are selected in terms of link spectral efficiency which is a typical measure to analyze the efficiency of a digital modulation method [10]. These two parameters have also been proved as key independent variables for regression analysis to explain progress of wireless technology from several literatures [11][12]. It should be noted that all the data being used in this study have been collected in accordance with the theoretical specifications in order to minimize the variations associated with transmission environment such as service providers or operating locations. The data collected therefore represents an upper bound of the performance of such technologies and the reader should be advised that the performance could be significantly lower from the one presented in average radio frequency (RF) environmental conditions. However, to assess the progress over time, it is best to consider a single condition and this is offered by looking at peak performance [13]. Moreover, the later versions of same technology, which usually focus on stability than performance, are not considered since the goal of this study is to characterize the progress of the leading wireless technology. In line with this, commercialized years are used in a sense of fully-operational adoption timing by end-users as an official mobile service.

A. HSDPA

High speed downlink packet access (HSDPA), which is the early phase of high speed packet access (HSPA) standard, is a digital packet-based service in the 3GPP WCDMA radio format [14]. This technology occupies 5 MHz bandwidth to achieve data rate of up to 42.2 Mbps from 3GPP release 7 which has decreased the latency and improved quality of real-time application such as VoIP [15]. The first HSDPA commercial service was launched by SK Telecom in 2006.

B. WiMAX

Worldwide interoperability for microwave access (WiMAX) is characterized by its high mobility and accessibility, which enables users to access the Internet even when they are moving at speeds up to 120km/h [16]. After WiMAX was ratified as a global standard by the Institute of Electrical Electronics Engineers (IEEE) in September 2005, KT launched world's first commercial WiMAX service in July 2006. It operates in channel bandwidths 10 MHz and supports theoretical maximum throughput of 75 Mbps [17][18].

C. LTE

Long term evolution (LTE) is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using new techniques called adaptive modulation [19]. Its relatively large spectrum bandwidths, 20 MHz, allows operators to achieve peak theoretical throughput rates of up to 326.4 Mbps [20]. Features of LTE include bandwidth scalability and flexibility that can operate in both time division duplex (TDD) and frequency division duplex (FDD) modes [21]. LTE was first proposed by NTT DoCoMo and has been commercially adopted in 2010 [22].

D. HSPA+

HSPA evolved (HSPA+) is a later version of HSPA standard using 3GPP release 9 or beyond [23]. It utilizes aggregated data pipe comprised of dual, quadruple, or octuple carriers. Each carrier uses 5 MHz and provides a maximum rate of 84 Mbps [24]. Its multi-carrier feature can benefit overall network by balancing the load as well as improving transmission quality of cell edge. World's first HSPA+ consumer service has been launched jointly by ZTE and CSL in 2011 [25].

TABLE 1 DATA SET FOR FORECASTING MODEL

Generation	*Technology*	*Commercialized year*	*Bandwidth (kHz)*	*Bitrate (kbps)*
1G	*NTT*	*1979*	*25*	*0.3*
	NMT-450	*1981*	*25*	*1.2*
	AMPS	*1983*	*30*	*10*
	C450	*1985*	*20*	*5.28*
	TACS	*1985*	*25*	*8*
	NMT-900	*1986*	*12.5*	*1.2*
2G	*TDMA*	*1990*	*30*	*48.6*
	CT2	*1991*	*100*	*72*
	JDC	*1991*	*25*	*42*
	GSM	*1992*	*200*	*270.833*
	DCS 1800	*1992*	*200*	*270.833*
	DECT	*1993*	*1728*	*1152*
	PDC	*1993*	*25*	*42*
	iDEN	*1994*	*25*	*64*
	CDMA	*1995*	*1250*	*1228.8*
	GPRS	*2001*	*200*	*270.833*
	EDGE	*2001*	*200*	*812.5*
3G	*CDMA2000*	*2001*	*1250*	*1228.8*
	WCDMA	*2001*	*5000*	*5760*
	HSDPA	*2006*	*5000*	*42200*
4G	*WiMAX*	*2006*	*10000*	*96000*
	LTE	*2010*	*20000*	*326400*
	HSPA+	*2011*	*5000*	*84000*

IV. REGRESSION MODEL

As advised from similar studies [11][12], logarithmic transformation has been utilized to the independent variables for regression model due to the characteristics of exponentially growing parameters over time. In order to select the best model for the forecast, five different regression models have been tested and statistical superiority can be found in model 3 (see Table 2.) Table 3 summarizes the specific results from this model. The R^2 value of 0.828 with p-value of 0.000 proves the statistical significance of the model that can explain 82.8% the change of 19 technologies. It should be noted that, conservatively though, t-test significance of bandwidth is higher than commonly accepted level, 0.181 (> 0.05.) However, additional diagnostics shown in Table 2 have shown that worsening effect of this variable on the overall model is less than the effect from excluding this variable from the model in terms of forecasting purpose, hence it has been included as an important variable, rather than fitted variable [26]. In addition, it has been also proven from the Collinearity statistics that no inter-relationship between two variables exists. With these results, we obtain the regression equation as follows.

$$Y_{Comm} = -2.532 \cdot X_{LBW} + 6.651 \cdot X_{LBR} + 1984.411 \quad (1)$$

This regression equation is then used as a forecasting model by substituting log transformed value of post-2001 technologies for X values. The forecasting result is shown in the Table 4.

As expected from high R^2 from up-to-2001 technologies, the regression model makes a quite close forecast on post-2001 technologies. The accuracy can be obtained statistically by mean absolute deviation (MAD) of 1.2520 years.

V. TFDEA MODEL

Next, we applied TFDEA to this same data set. Similar to data transformation and model verification for better results in regression model, it is necessary to determine appropriate application model for TFDEA. Here, we found the best model to be one input (Bandwidth) and one output (Bitrate) with input-oriented model. The reason can be explained by the term ‘Fundamental limit’ from the Information theory. In the subject of wireless communication technology, ultimate limitation that cannot be overcome or replaced is the radio spectrum that comes from the nature. The scarcity value of frequency is well explained by the recent spectrum auction records indicating that 1.8 GHz was auctioned off at $0.9 billion in Korea in 2011 and 1.7 GHz auction netted $13.7 billion in U.S. in 2006 [27]. Borrowing terms from the spectral efficiency, this field of research can be defined as an endeavor to obtain data throughput with minimum usage of available frequencies [28]. Therefore, it is reasonable to assume that development of wireless communication technology has been guided by optimum use of bandwidth generating better throughput rather than by maximum throughput making a full use of bandwidth. In addition, constant return to scale (CRS) has been applied to the model since bandwidth is the range of frequencies, hence the average product is not affected by changes in scale size [29]. The TFDEA model used in this application is summarized in Fig.1.

TABLE 2 MODEL VERIFICATION

Regression model	Independent variable	Dependent variable	R^2	p-value	MAD
Model 1	X_{LBW}	Y_{Comm}	0.501	0.001	2.1961
Model 2	X_{LBR}	Y_{Comm}	0.806	0.000	1.3376
Model 3	X_{LBW}, X_{LBR}	Y_{Comm}	0.828	0.000	1.2520
Model 4	$\frac{X_{LBR}}{X_{LBW}}$	Y_{Comm}	0.124	0.139	33.7205
Model 5	$Log_{10}\frac{X_{BR}}{X_{BW}}$	Y_{Comm}	0.633	0.000	6.0813

$X_{(L)BW}$: (Log transformed) Bandwidth
$X_{(L)BR}$: (Log transformed) Bitrate
Y_{Comm}: Estimated commercialized year

TABLE 3 SUMMARY OF MULTI-REGRESSION ANALYSIS RESULTS

Model suitability			Unstandardized Coefficients			Collinearity Statistics	
R^2	p-value		β	Std. Error	Sig.	VIF	Tolerance
0.828	0.000	(Constant)	1984.411	2.166	0.000		
		Bandwidth	-2.532	1.812	0.181	4.066	0.246
		Bitrate	6.651	1.209	0.000	4.066	0.246

TABLE 4 FORECASTED YEAR BY REGRESSION ANALYSIS

Technology	Actual year	Forecasted year
HSDPA	2006	2005.81
WiMAX	2006	2007.42
LTE	2010	2010.19
HSPA+	2011	2007.80
	MAD:	1.2520

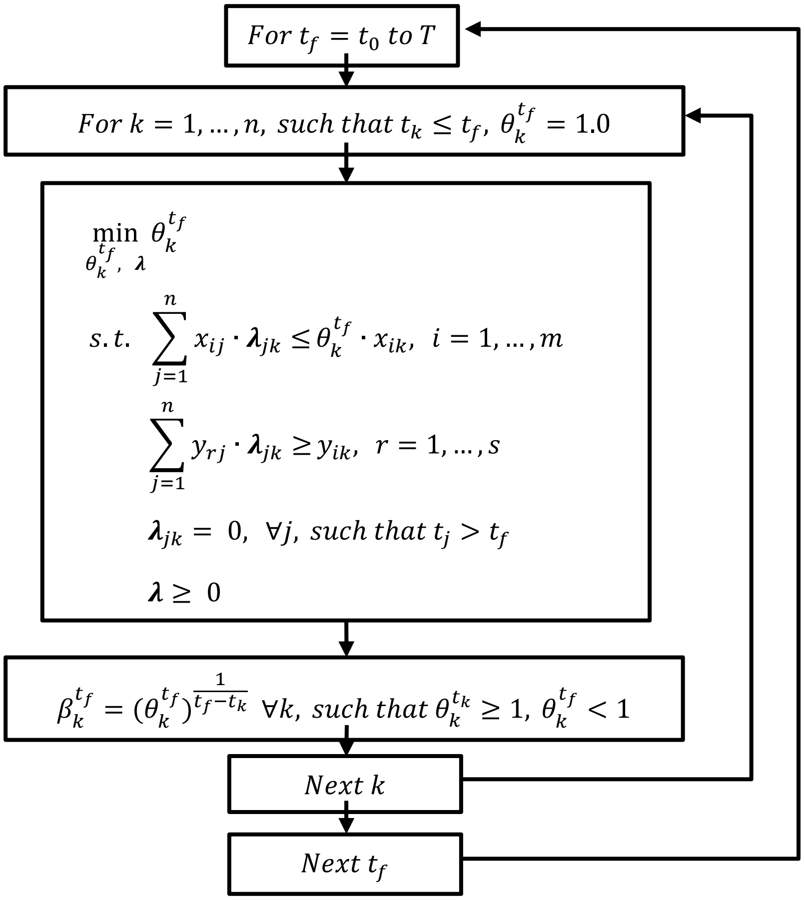

Figure 1 TFDEA model process

Briefly, x_{ik} represents the ith input and y_{rk} represents the rth output of technology k. The variables for the linear program underlying DEA are $\boldsymbol{\lambda}_{jk}$ and $\theta_k^{t_f}$. The variable $\theta_k^{t_f}$ also serves as the objective function and represents the amount of input which should be saved by technology k at time period t_f if it were state-of-the-art at that time. The variables, $\boldsymbol{\lambda}_{jk}$, describe how much of technology j is used in setting a target of performance for technology k. For more comprehensive treatment of TFDEA, the interested reader is referred to original study [30].

Table 5 presents the result of TFDEA model on up-to-2001 technologies. As one would expect, some technologies had been state-of-the-art in a certain period of time from their release and were superseded by future technologies. These dynamics are captured in $\beta_k^{t_k}$ for each technology and then averaged to 1.1521, indicating that bandwidth of wireless technology has decreased by 15.21% per year for any fixed level of bitrate.

The average rate of change can then be used to project virtual technologies on the frontier to the future. In other words, post-2001 technologies are to be forecasted by multiplying average rate of change raised to the power corresponding to their super-efficiencies being measured from frontier 2001. Table 6 shows the final result of this forecast process. It is identified that TFDEA provides extremely accurate forecasts with mean absolute deviation (MAD) of 0.4191 years (less than half a year.)

VI. DISCUSSIONS

Fig. 2 provides a visual comparison of the technology forecasts from two different models. Two axes are actual year and forecasted year, therefore, technologies on the diagonal line would have been commercialized at exactly the year forecasted given their specifications. As seen in the figure, forecasts from the TFDEA (triangle icons) generally show closer distance from the diagonal line than those from the regression model (square icons.)

TABLE 5 RESULTS OF TFDEA

k	Technology	Commercialized year (t_k)	Efficiency at time of release ($\theta_k^{t_k}$)	Efficiency at frontier year (θ_k^{2001})	Annual rate of change ($\beta_k^{t_k}$)
1	NTT	1979	1	0.002954	1.303114
2	NMT-450	1981	1	0.011815	1.248469
3	AMPS	1983	1	0.082051	1.149023
4	C450	1985	0.792	0.064985	0
5	TACS	1985	0.96	0.078769	0
6	NMT-900	1986	0.288	0.023631	0
7	TDMA	1990	1	0.398769	1.087171
8	CT2	1991	0.428571	0.177231	0
9	JDC	1991	1	0.413538	1.092316
10	GSM	1992	0.806051	0.333333	0
11	DCS 1800	1992	0.806051	0.333333	0
12	DECT	1993	0.396825	0.164103	0
13	PDC	1993	1	0.413538	1.116697
14	iDEN	1994	1	0.630154	1.068195
15	CDMA	1995	0.384	0.241979	0
16	GPRS	2001	0.333333	0.333333	0
17	EDGE	2001	1	1	0
18	CDMA2000	2001	0.241979	0.241979	0
19	WCDMA	2001	0.283569	0.283569	0

TABLE 6 FORECASTED YEAR BY TFDEA

Technology	Actual year	Forecasted year
HSDPA	2006	2006.16
WiMAX	2006	2005.33
LTE	2010	2010.82
HSPA+	2011	2011.02
	MAD:	0.4191

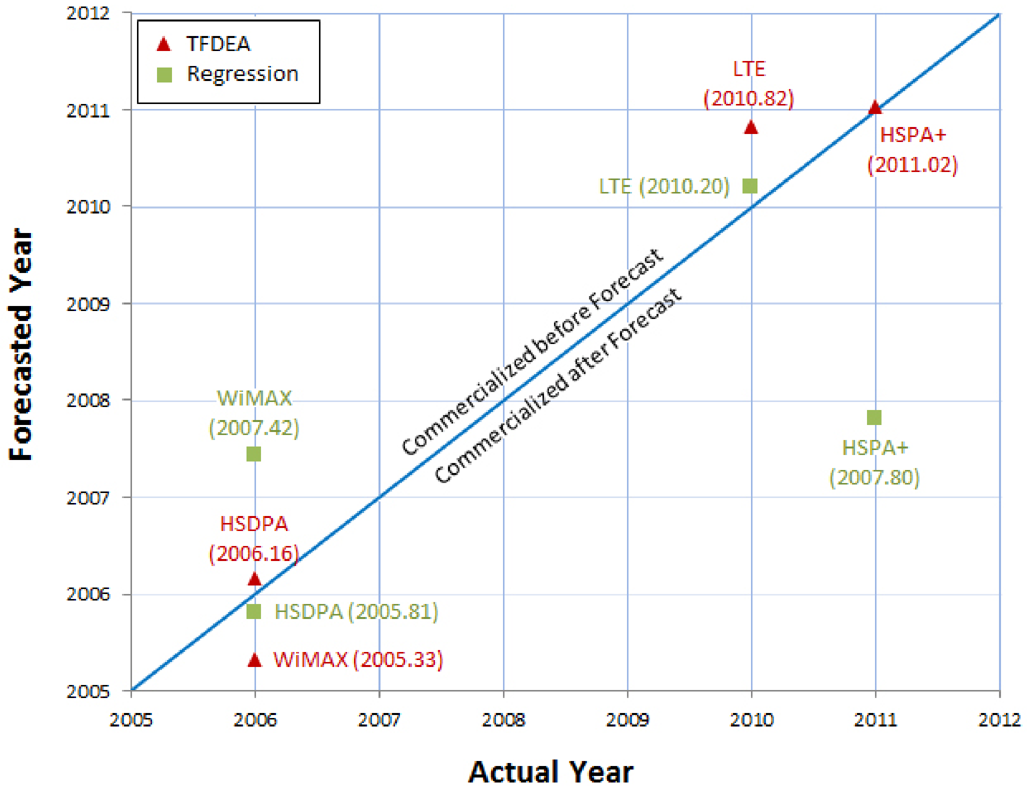

Figure 2 Comparing actual and forecasted year

One notable technology is HSPA+ which being identified as an outlier for regression model whereas most accurately forecasted by TFDEA. This discrepancy serves to underline how each model utilizes given data set differently when they make a forecast. As seen in the Table 1, HSPA+ technology relatively generates a slow bitrate using a small bandwidth compared to its previous technology, LTE. However, HSPA+ is as advanced technology as LTE in terms of spectral efficiency; HSPA+ has 16.80 and LTE has 16.32. Regression model sensitively reflects this scale difference on its forecast since it relies on fixed coefficients from the weighted regression function. Once these coefficients are determined, they can't be changed or selectively applied to the forecast.

In contrast, TFDEA can customize the starting point of each forecast by effective year from super-efficiency which may be denoted by Eq. (2):

$$t_k^{eff} = \frac{\sum_{j=1}^{n} t_k \cdot \boldsymbol{\lambda}_{kj}}{\sum_{j=1}^{n} \boldsymbol{\lambda}_{kj}} \qquad \forall k \tag{2}$$

where t_k^{eff} the effective year of technology k, t_j the release year of a reference state-of-the-art (SOA) decision making unit (DMU) j, $t_k$the release date of the no longer efficient decision making unit (DMU) k that used to be on the state-of-the-art (SOA) frontier, and $\boldsymbol{\lambda}_{kj}$ the weight of the reference observation j on the efficiency score of observation k. Once the effective year for each technology has been determined, the forecasting can be made by Eq. (3):

$$t_k^f = \frac{\ln(\theta_k^{SE})}{\ln(\beta_{Avg}^{t_f})} + t_k^{eff} \quad \forall k \tag{3}$$

where t_k^f is the forecasted year of technology k, θ_k^{SE} the input-oriented super-efficiency of technology k, $\beta_{Avg}^{t_f}$ the average rate of change until frontier year t_f, and t_k^{eff} the effective year of technology k. The main advantage of this approach is that it enables each technology to have their own benchmark(s) on which their best forecast should be based. For the case of HSPA+, TFDEA sets EDGE technology from 2001 as its forecasting benchmark while regression model maintains constant intercept of 1984.411. This distinct feature of TFDEA, of course, may not always result in better forecast than regression model. The point is forecaster has to have understanding on the characteristics of data set being analyzed so that the optimum model can be selected and properly applied.

Another key element that forecaster should keep in mind is the trend of technology progress. As observed in many industries, technology often has generations or specific time periods when it progresses in certain directions. This contradicts forecasters' hope of conveniently using fixed key parameters over time for the forecast. In wireless communication technology for example, parameters related to the spectral efficiency have proven their significance as key indicators including this study. However, the direction of progress seems to be changing these days. Especially since early-4G technologies, they have shown tendency to focus on providing high throughput to more people in certain cell [31]. Further, 4G wireless technologies are expected to incorporate new features called carrier aggregation or self-optimizing networks (SON) so that deployment cost can be reduced while providing similar spectral efficiencies with previous technologies [32]. These trends of future technology wouldn't be easily explained only with bandwidth and bitrate parameters. Therefore, as Martino pointed out in his book [33], forecaster should be armed with knowledge about technology itself as well as technological forecasting tools in order to make a precise forecast.

VII. CONCLUSION

Both regression and TFDEA results indicate that wireless communication technology had been evolved incrementally until 2001 and this moderate change was replaced by drastic advancement from 4G network standards thereafter. This trend rendered TFDEA model that measures the deviation from the frontiers formed by superior technologies, as compared with regression model that measures the deviation from the averaged trend, possible to capture the technology changes more accurately.

As frequently addressed in the field of technology forecasting, neither one method can be inherently better than others nor high accuracy proven from the past guarantees its suitability for the next forecast. In line with this, there is no intent here to disparage regression analysis or its use in the forecasting; instead, the focus of this research is to provide comparative information by scrutinizing two different aspects so that forecasters can select more suitable model for their purposes.

REFERENCES

[1] T. R. Anderson, K. Hollingsworth, and L. Inman, "Assessing the rate of change in the enterprise database system market over time using DEA," in *PICMET '01. Portland International Conference on Management of Engineering and Technology. Proceedings Vol.1: Book of Summaries (IEEE Cat. No.01CH37199)*, p. 203.

[2] T. Anderson, R. Fare, S. Grosskopf, L. Inman, and X. Song, "Further examination of Moore's law with data envelopment analysis," *Technological Forecasting and Social Change*, vol. 69, no. 5, pp. 465-477, 2002.

[3] O. Inman, T. Anderson, and R. Harmon, "Predicting U.S. jet fighter aircraft introductions from 1944 to 1982: A dogfight between regression and TFDEA," *Technological Forecasting and Social Change*, vol. 73, no. 9, pp. 1178-1187, 2006.

[4] T. R. Anderson, T. U. Daim, and J. Kim, "Technology forecasting for wireless communication," *Technovation*, vol. 28, no. 9, pp. 602-614, 2008.

[5] M. Flament et al., "An approach to 4th generation wireless infrastructures-scenarios and key research issues," in *Vehicular Technology Conference 1999 IEEE 49th DOI 101109VETEC1999780715*, 1999, vol. 2, p. 1742--1746 vol.2.

[6] P. Asmundson, D. Allen, C. E. Steidtmann, K. Thompson, and C. Brodeur, "The Impact of 4G Technology on U.S. Competitiveness," New York, 2011.

[7] C. Edwards, "The phoney war," *Engineering & Technology*, vol. 3, no. 11, pp. 72-75, 2008.

[8] M. Altschul, C. McCabe, R. F. Roche, and B. M. Josef, “Comments of CTIA - the wireless association,” Washington D.C., 2011.

[9] Qualcomm, “Evolution of Wireless Applications and Services,” San Diego, 2007.

[10] D. N. Hatfield, “Measures of spectral efficiency in land mobile radio,” in *25th IEEE Vehicular Technology Conference*, 1975, pp. 23-26.

[11] M. A. Amaya and C. L. Magee, “The progress in wireless data transport and its role in the evolving internet,” 2008.

[12] J. Kim, T. Daim, and T. Anderson, “A look into the future of wireless mobile communication technologies,” *Technology Analysis & Strategic Management*, vol. 22, no. 8, pp. 925-943, Nov. 2010.

[13] G. E. Moore, “No exponential is forever: but ‘Forever’ can be delayed!,” in *2003 IEEE International Solid-State Circuits Conference, 2003. Digest of Technical Papers. ISSCC.*, 2003, vol. 1, pp. 20-23.

[14] A. Technologies, “Signal Studio for 3GPP W-CDMA HSPA Technical Overview,” 2009.

[15] J. Derksen, R. Jansen, M. Maijala, and E. Westerberg, “HSDPA performance and evolution,” 2006.

[16] H.-W. Kim, Y.-S. Jeon, and S. Choi, “Attractiveness of alternatives in information systems continuance: A case of WiMAX,” Taipei, 2011.

[17] K. Sivanesan, J. Xiao, R. Q. Hu, and G. Wu, “Code Book Based CL-MIMO for DL Wimax Rel. 1.5: System Level Performance Analysis,” in *2009 IEEE International Conference on Communications*, 2009, pp. 1-5.

[18] 4G wireless broadband service, “What is the actual throughput (data transfer rate) of WiMAX Technology?,” 2011.

[19] Motorola, “Long Term Evolution (LTE): A Technical Overview,” 2010.

[20] S. Signell, “Background, overview and evolution of wireless communication systems,” in *Applied Signal Processing*, Royal Institute of Technology, 2011.

[21] 3G americas, “The Mobile Broadband Future: HSPA+ and LTE,” 2010.

[22] J. Gozalvez, “First Commercial LTE Network,” *IEEE Vehicular Technology Magazine*, vol. 5, no. 2, pp. 8-16, Jun. 2010.

[23] Qualcomm, “HSPA+ R8,” San Diego, 2008.

[24] Qualcomm, “HSPA+ advanced,” 2011.

[25] CSL Hong Kong, “CSL launches world’s first commercial grade LTE/DC-HSPA+ network,” 2012.

[26] S. T. Ziliak and D. N. McCloskey, “Size matters: the standard error of regressions in the American Economic Review,” *The Journal of Socio-Economics*, vol. 33, no. 5, pp. 527-546, 2004.

[27] M. R. Kelley, “The Spectrum Auction: Big Money and Lots of Unanswered Questions,” *IEEE Internet Computing*, vol. 12, no. 1, pp. 66-70, Jan. 2008.

[28] J. M. Kahn and K.-P. Ho, “Spectral Efficiency Limits and Modulation/Detection Techniques for DWDM Systems,” *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 10, no. 2, pp. 259-272, 2004.

[29] H. O. Fried, C. A. K. Lovell, and S. S. Schmidt, *The measurement of productive efficiency and productivity growth*, 1st ed. New York: Oxford University Press, 2008, p. 638.

[30] O. L. Inman, “Technology forecasting using data envelopment analysis,” Portland State University, 2004.

[31] S. Sinanovic, N. Serafimovski, H. Haas, and G. Auer, “System Spectral Efficiency Analysis of a 2-Link Ad Hoc Network,” in *IEEE GLOBECOM 2007-2007 IEEE Global Telecommunications Conference*, 2007, pp. 3684-3688.

[32] M. Rumney and D. Tandur, “3GPP LTE / LTE-A Standardization: Status and Overview of Technologies,” Warsaw, 2011.

[33] J. P. Martino, *Technological Forecasting for Decision Making*, 2nd ed. North-Holland: McGraw-Hill, 1993.