

Spectrum auction in Korea: design and implication

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Abstract

Since the legislation of spectrum auction in 2011, three auctions have been implemented to achieve policy objectives of the Korean government. I explore what are the issues of spectrum assignment of each auction, how each auction was designed to resolve the issue, and what implications are derived from each. I believe that spectrum auction has successfully allocated spectrum by market mechanism, where operators express their true willingness to pay for the spectrum blocks. Even though there are challenges to overcome, spectrum auction has become a stable mechanism and will be expected work well for future events.

Keywords: spectrum auction, simultaneous multiple round ascending auction

1. Introduction

As an important and limited national resource, spectrum is managed by the national authorities that determine who can use it under what conditions. Especially, since the spectrum used for mobile telecommunication has a tremendous market value, its assignment has become an important policy issue in many countries. In this context, spectrum auction has been developed to overcome the cons of beauty contest, achieve socially efficient allocation and collect revenues for the government. In other words, it can guarantee fairness in selecting operators and charge the price equal to the market value of the spectrum.

The spectrum policy has taken major role in the development of mobile telecommunications market and related industries in Korea. To foster the development of information and communications technology (ICT) and telecommunications market, the Korean government has driven the market by selecting operators and awarding spectrum to them accordingly. Since spectrum is the essential resource providing mobile telecommunication service, spectrum policy roles practically as mobile telecom market entrance policy.

In 1984, when the first mobile operator, Korea Mobile Telecommunications Services Corporation (later acquired by and switched to SK Telecom) started car phone analog service, 800MHz frequency band is assigned to the company. And in 1996, when SK Telecom and 2nd mobile operator, Shinsegi Telecom, began the digital CDMA cellular service, additional 800MHz band is assigned. Also when three new commercial PCS networks started mobile service in 1997, 1.8GHz frequency band is assigned to the operators, KTF, LGT, and Hansol PCS. When IMT-2000(3G) service is launched, 2.1GHz band is supplied to the market in 2001. Re-assignment of 800MHz and 1.8GHz band, along with new assignment of 900MHz band is carried out in 2011.

Proper assignment of spectrum resulted in successful developments of new technologies, such as CDMA,

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and first commercial deployment of LTE-Advanced, and so on. That is, timely assignment of spectrum made it possible to adopt new technologies. Recently, since the introduction of 4th generation mobile telecommunication technology, such as Long Term Evolution (LTE), and explosive increase of mobile traffic, proper supply of broadband spectrum has become an important issue of spectrum management in many countries including Korea. Within the ICT ecosystem and data-centric mobile environment, spectrum management policy is still very important.

With the great importance of spectrum policy, the Korean government tried to improve the spectrum management policy. The Radio Waves Act, the Korean law governing spectrum policy, recognizes the importance of efficient utilization of spectrum, dictates to promote social welfare, through (1) efficient use and management of radio spectrum, (2) fostering technology development on radio spectrum, (3) promotion of radio spectrum industry, and research institution.

However, it is not until June 2010 when spectrum auction is introduced to the Radio Waves Act. Before the legislation, it is believed that government can manage the spectrum and telecom market quite effectively. It was the regime of so-called “command and control.” But since the mobile market and technology evolve rapidly, the cons of beauty contest as spectrum assigning mechanism became problematic, thus market-based approach, the spectrum auction, is finally introduced. The Act went into effect on January 2011.

Article 11 of the Radio Waves Act dictates that when radio spectrum is assigned with its charge, it has to be determined by price competition, except for special circumstances, such as competing demand for the spectrum does not exist. In that exceptional case, the Korean regulatory body, the Ministry of Science, ICT and Future Planning (MSIP), can assign spectrum to the entity at the price determined by MSIP.

Since the legislation, three spectrum auctions were carried out in Korea. But it is surprising that the details of Korean spectrum auctions are unknown and the proper comparison and analysis of them are negligent in academics. There are the public notices of the Korean regulatory body (KCC, 2011a; MSIP, 2013a, MSIP, 2016a), but it is hard to see under what circumstances the auction is designed and conditions are given. Papers from Korea Information Society Development Institute (KISDI) also dealt with Korean spectrum auction, but it primarily focused on individual auction. (Kim et al., 2014)

My goal is to analyze systematically three spectrum auctions in Korea, with respect to its design, result, and implication. Therefore, this paper deals with a very practical issue. The structure of the paper is as follows. I review three spectrum auctions implemented in 2011, 2013, and 2016, respectively. For each auction, I explain the mobile market status, the issues regarding spectrum assignment, the auction design, the result, and evaluation. In section 5, I conclude with discussions and future challenges.

2. First spectrum auction (2011): standard SMRA

The first spectrum auction in Korea was held on August 2011. Three spectrum blocks, 10MHz bandwidth in 800MHz band, 20MHz bandwidth in 1.8GHz band, and 20MHz bandwidth in 2.1GHz band, are auctioned.

2.1 Market status

There are three mobile network operators (MNOs) in Korea, SK Telecom (SKT), Korea Telecom (KT) and LGU plus (LGU+), which have market share of about 50%, 30%, 20%, respectively for more than a decade. Before the spectrum auction, SK Telecom, Korea Telecom, and LGU plus, own 90MHz, 80MHz, and 40MHz of spectrum respectively. The table below shows spectrum holding of MNOs before 2011 auction for each band.

Table 1. Spectrum holding of MNOs before 2011 auction (unit: MHz)

	SKT	KT	LGU+
800/900MHz	30	20	20
1.8GHz	–	20	20
2.1GHz	60	40	–
Total	90	80	40

Note: WiBro spectrum holding in 2.3GHz band is not included (SKT 27MHz, KT 30MHz)

Just before the auction, LTE rollout and service competition was initiated in Korean mobile market. For spectrum assigned in May 2010 and re-assigned in July 2011, its technology requirement is 3G or higher, therefore it is allowed to use advanced technology, such as LTE. And using the band, in July 2011, LGU plus and SK Telecom began to provide LTE service with 20MHz (2×10MHz) and 10MHz (2×5MHz) bandwidth, respectively, in 800MHz band. Later in January 2012, Korea Telecom started LTE service in 1.8GHz band, which has to be vacated by terminating legacy 2G service. With these market environment, mobile operators wanted to acquire additional spectrum to take advantageous position in LTE competition.

2.2 Auction design

Since it was the first spectrum auction implemented in Korea, it is designed as one of the traditional auction type, simultaneous multiple round ascending auction (SMRA). At that time, new type of auction, combinatorial clock auction (CCA) has started to be implemented in a few countries.¹⁾ But since there are only three spectrum blocks to be auctioned, SMRA is thought as a proven auction type and suitable to be used in Korea. SMRA is widely used in many countries for spectrum auction since it was developed by Federal Communications Commission (FCC) of the United States.²⁾ It is an extension of ascending auction to the case of multiple goods, where the prices and winners of each block are determined simultaneously until none is willing to bid anymore.

To promote competition and ensure fair competition in the market, regulatory conditions are given. If potential market entrant applies for business approval and spectrum assignment at the same time, and passes business approval process, a priority to pick spectrum band will be given. However, there was no potential market entrant applied, thus eventually three existing operators competed in spectrum auction. The other condition is that two service providers who already have 2.1GHz band, SK Telecom and Korea Telecom, are not allowed to participate in the auction in 2.1GHz band.

The auction rule is basically a simple simultaneous multiple round ascending auction (SMRA). Each bidder can bid for one block in each round, and when a bidder becomes the winner of a block it cannot bid until other bidder wins against the current winner. The auction is finalized if there is no bid for all spectrum blocks.

2.3 Auction result

The auction is concluded in 83 rounds, lasting 9 days. The bidding competition only occurs in 1.8GHz band, whose winning price (995 billion KRW) is about twice of its reserve price.³⁾ The winner of 1.8GHz band is SK Telecom. The other bands (800MHz, 2.1GHz) were sold at the minimum price (261 billion KRW, 446 billion

1) Cramton (2013) discusses theoretical aspects of CCA, and Ofcom (2012) shows real implementation of spectrum auction using CCA.

2) Refer to FCC (2006) for detailed auction rules of SMRA.

3) For spectrum auctions in Korea, starting price is set equal to the reserve price.

KRW), respectively. Winners of each are Korea Telecom and LGU plus.

Table 2. Result of 2011 auction

Band	Bandwidth	Duration (year)	Reserve price (KRW)	Winning bid (KRW)	Winning bidder
800MHz	10MHz	10	261 B	261 B	KT
1.8GHz	20MHz	10	445.5 B	995 B	SKT
2.1GHz	20MHz	10	445.5 B	445.5 B	LGU+
Total	50MHz	–	–	1,701.5 B	–

Source: KCC(2011b)

By imposing regulatory condition, LGU plus is able to acquire 2.1GHz band at the reserve price. SK Telecom wins 1.8GHz band, and Korea Telecom wins 800MHz band (so-called “Extended 850” band). Assigned frequency bands are used to provide LTE except for Korea Telecom. From Table 3 below, spectrum holding of three MNOs has become fairly even in each band after the auction, even though total spectrum holding still varies among operators.

Table 3. Spectrum holding of MNOs after 2011 auction (unit: MHz)

	SKT	KT	LGU+
800/900MHz	30	30	20
1.8GHz	20	20	20
2.1GHz	60	40	20
Total	110	90	60

2.4 Evaluation

The auction is successfully implemented to achieve policy goals. It could guarantee fairness and transparency of spectrum assignment, and its price, which grants usage right of national resource, is determined by market mechanism. Also with regulatory conditions, the uneven spectrum holding of MNOs can be alleviated. From the common spectrum band among operators, we could expect economies of scale in mobile handset production.

However, bidding restriction in 2.1GHz band could be viewed as special treatment to the 3rd MNO, LGU plus, since it could win the band without any competition. With sole competition by two other operators occurred in 1.8GHz band over 83 rounds, some may view it as too much competition and it is caused by the auction design, ascending open type auction. Since the band was eventually won by the market dominant operator, SK Telecom, this perception might be true. But auction itself is the process to discover the true value of the good, spectrum. Also regardless of auction type, the bidder with financial superiority can take an advantageous position. Nevertheless, we could consider sealed-bid or hybrid type of auction to relieve the anxiety of perpetual competition. There are views that winner may suffer from so-called winner’s curse that the price is twice of other bands. I cannot conclude that it really occurred or not, but compared to the auction result in 2013, the price does not seem to be above reasonable level.

After 2011 auction, the MSIP announced the mid-long term spectrum supply policy plan, Mobile

Gwanggaeto Plan, in January 2012 to supply spectrum in a more predictable and systematic way. Auctions in 2013 and 2016 were basically carried out based on the plan, even though there were some minor changes.

3. Second spectrum auction (2013): multi-bandplan auction

The second spectrum auction in Korea is held on August 2013. Spectrum blocks in 1.8GHz and 2.6GHz band were candidate bands to be auctioned.

3.1 Market status and issues

Since the introduction of LTE in 2011, LTE subscription base has increased rapidly to replace 2G and 3G service. And operators wanted to enhance LTE service by utilizing broadband spectrum bandwidth, mainly 20MHz downlink in the frequency division duplex (FDD) environment.

Therefore, the objective of spectrum auction is to provide spectrum suitable for LTE-Advanced service. Two broadband blocks in 2.6GHz band were secured to be provided, but there were issues in 1.8GHz band. That is, if D block, which itself is a narrowband, is supplied and acquired by Korea Telecom, it becomes a broadband with KT's adjacent band. There is another broadband, C block in 1.8GHz band.

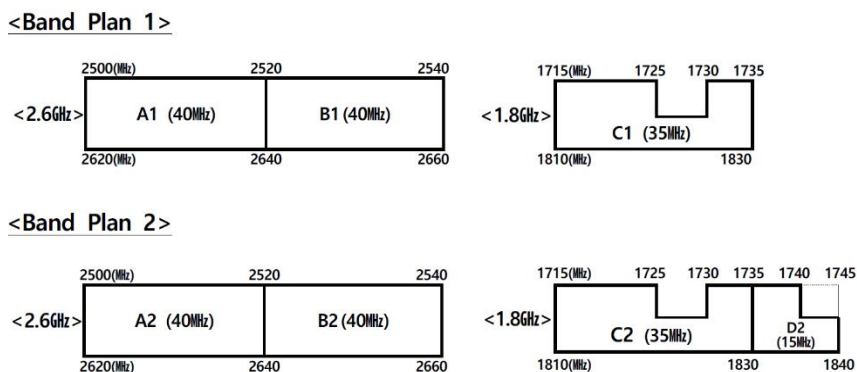
Since there was a fierce competition who can start broadband LTE-A service in the first place, operators debated over whether D block should be included or not. Some argued that it has to be excluded to ensure fair competition, others argued that it should be supplied to use spectrum efficiently.

Also there is another concern on limited competition in the auction. Depending on the inclusion of D block, there are only 3 or 4 blocks to be auctioned, whereas 3 MNOs are potential bidders. If there is not enough bidding competition, fair market value of the spectrum cannot be retrieved.

3.2 Auction design

For the issues described above, the MSIP was not be able to determine whether to include D block to the auctioning bandplan. The solution is to construct two bandplans – bandplan 1 does not include D block whereas bandplan 2 does - and auction them to determine the winning bandplan, winning blocks, winning price, and winners at the same time.

Figure 1. Bandplan of 2013 auction



Source: MSIP(2013a)

Combinatorial clock auction (CCA), developed in Europe, has been implemented in many countries at the time, and therefore CCA is considered as one of the candidate auction design. The CCA is a modification of clock-proxy auction to alleviate the exposure problem. It is composed of two stages, where the first stage determines the number of blocks each bidder wins, and the exact frequency location is determined in the second stage.

It can work pretty well with new frequency bands, such as 2.6GHz band which is constituted by contiguous blocks like many European countries, where each mobile network operator does not have preference over the location in the band. However, it is doubtful that efficient outcome can be derived if one operator has a strong preference over a specific frequency block, for example, when the auction is carried out over bands between operator's owned blocks. Especially, when one operator secures broadband spectrum by winning adjacent block in the auction, negative externalities could arise to the other operators. Therefore, they might bid on that block to increase the price over their value. Hence it is questionable that price can be fully revealed in this situation. This concern is similar to Jehiel et al. (1996) in that they present an efficient mechanism to sell a nuclear weapon where everyone except the owner is affected by negative externalities of the weapon.

Also, unlike European CCA case with many generic blocks are supplied, since broadband blocks are constituted in advance by Korean policy agency the need for CCA is negligible. Also it is too complicated to be applied with only one experience of spectrum auction. It is concluded that CCA may not be optimal auction format under the 2013 Korean situation.

With these background, the second spectrum auction in Korea is designed with revolutionary bandplan auction. Within the bandplan auction design, it is possible to indirectly compete for D block, which does not have much value to some bidders.

Auction format can be classified as hybrid, since there are 50 rounds of simultaneous multiple round ascending auction, and one final sealed bid auction in case the auction is not concluded within 50 rounds by SMRA. Hybrid type is introduced to ease the possibility of too much competition to the level of winner's curse.

When an auction is composed with two different rules, careful design is required to prevent the incentive to abuse the auction rule when switching. In the auction design, the maximum bid in sealed bid auction, which is determined by how each bidder bids over SMRA stage, is therefore introduced. It is similar to the relative cap of CCA, where the bid in supplementary round is limited by the bid history of primary rounds. With maximum bid rule, we believe that it is optimal to bid truthfully at SMRA stage for each bidder.

Similar to the first auction in 2011, some regulatory conditions are also given in the second auction. To ensure fair competition of broadband LTE-A, MSIP imposed service restriction depending on each contingency. For bandplan 1, where D block is not included, bidding restriction in C block is additionally imposed.

3.3 Auction result

The auction is concluded in 50 rounds of ascending rounds and 1 sealed bid round, lasting 10 days. Bandplan 2 is determined as the winning bandplan, and D block is won by Korea Telecom, by bidding 1,050 billion KRW. Korea Telecom is able to acquire D block as wished, but the company has to pay the additional price for it.

SK Telecom is the winner of C block by bidding 900 billion KRW, and LGU plus won B block of 2.6GHz band with 479 billion KRW. With the regulatory conditions imposed, SK Telecom has to return 20MHz of 1.8GHz band acquired in 2011 auction. However, SK Telecom could utilize broadband spectrum using installed facilities by the frequency band tuning in same band. In contrast to the other operators, LGU plus has to invest in new band, 2.6GHz, even though it is a complete 2x20MHz broadband spectrum block.

Table 4. Result of 2013 auction

Block (Band)	Bandwidth	Duration (year)	Reserve price (KRW)	Winning bid (KRW)	Winning bidder
A(2.6GHz)	40MHz	8	478.8 B	–	–
B(2.6GHz)	40MHz	8	478.8 B	478.8 B	LGU+
C(1.8GHz)	35MHz	8	673.8 B	1,050 B	SKT
D(1.8GHz)	15MHz	8	288.8 B	900 B	KT
Total	130MHz	–	–	2,428.8 B	–

Source: MSIP(2013b)

Table 5. Spectrum holding of MNOs after 2013 auction (unit: MHz)

	SKT	KT	LGU+
800/900MHz	30	30	20
1.8GHz	35	35	20
2.1GHz	60	40	20
2.6GHz	–	–	40
Total	125	105	100

3.4 Evaluation

Assigned frequency bands were used to provide LTE-A service, and enhance LTE with carrier aggregation (CA) technology. I believe that timely assignment of spectrum made it possible to provide the most sophisticated and advanced service to the subscribers, which gives rises of social welfare. Also with even distribution of broadband spectrum, ground for fair competition is ensured.

The issue of whether to include D block, which is not solvable in a traditional way of arbitration, is resolved by the auction design, the bandplan auction. With the auction design, we can positively evaluate that bidders search for prices in ascending rounds and reveal their true value on each block in sealed bid round. Therefore, an efficient allocation is achieved by market mechanism.

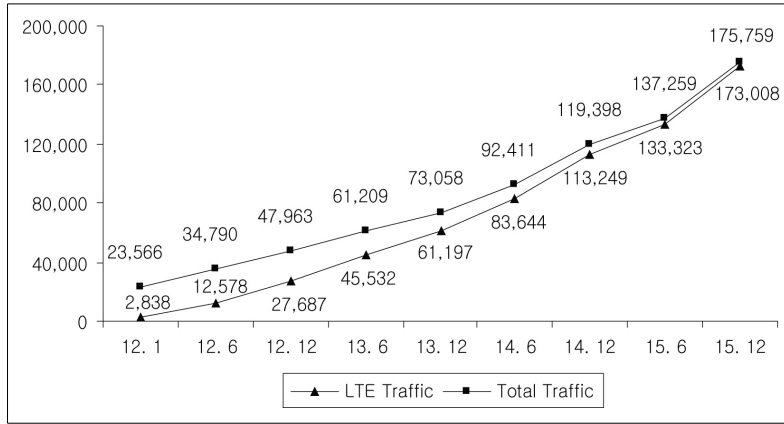
4. Third spectrum auction (2016): SMRA with activity rule introduced

The third spectrum auction in Korea was held in April 2016. Four spectrum bands, 700MHz, 1.8GHz, 2.1GHz, and 2.6GHz, were auctioned with total bandwidth of 140MHz.

4.1 Market status and issues

LTE service becomes popularized in Korea. Among 56.8 million mobile subscribers, 41.7 million people (71%) used LTE service as of December 2015. With faster transmission capability, mobile traffic of LTE user is much higher than that of 3G user. Total LTE traffic composes 98% of the total traffic generated monthly. As seen from Figure 2, mobile traffic continues to rise as LTE subscription increases and mobile ecosystem is vitalized.

Figure 2. Monthly mobile traffic trend in Korea (unit: TB/month)

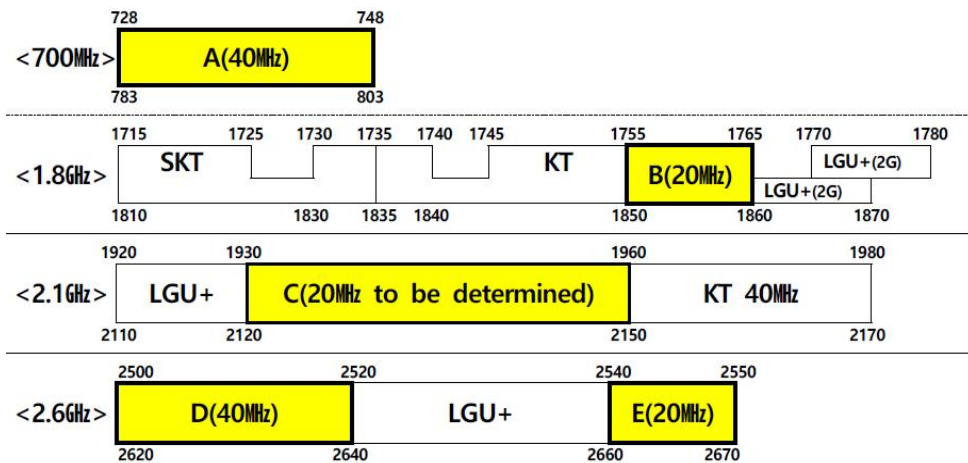


Source: Ministry of Science, ICT and Future Planning(<http://www.msip.go.kr>)

To accommodate the mobile traffic, which is expected to rise continually, operators demand for an additional spectrum. Their priority is still broadband spectrum, that is costly efficient to be deployed. But it seems that spectrum demand among operators could vary since the number of subscribers and total mobile traffic among them are different.

Spectrum bands that can be supplied in 2016 auction are much bigger than previous ones. In 700MHz band, which is digital dividend spectrum in Korea, one broadband block is available, and 20MHz block in 1.8GHz band, which is returned by SK Telecom after 2013 auction, is available. In 2.6GHz band, one broadband block that is unsold in 2013 auction, and another narrowband block is supplied. In 2.1GHz band, one 20MHz block is auctioned, but the exact frequency location will be determined after the auction. This is because the MSIP decided to re-assign 40MHz bandwidth to the existing user, SK Telecom, at the expiry in December 2016, and it is efficient to assign newly auctioned block adjacent to the operator whoever wins the auction.

Figure 3. Bandplan of 2016 auction



Source: MSIP(2016a)

4.2 Auction design

In previous two auctions, each operator was allowed to win only one block. The reason is that not only the spectrum supply was not enough but also the regulator wanted to ensure fair competition. But in 2016 auction there are many choices possible, 5 blocks and total bandwidth of 140MHz. Therefore, each operator should be able to choose whatever it need for the network operation, except that we still need a minimum requirement for fair competition. Therefore, total bandwidth won by each operator is capped by 60MHz, and one broadband block can be won by each. The C block is considered as broadband block since it can be adjacently assigned to any operator to form a broadband spectrum. It is similar to the situation of the D block in 2013 auction.

Auction format is hybrid type, 50 rounds of SMRA plus the final round of sealed-bid auction. In designing SMRA rules, the activity rule is introduced. Since each bidder can bid more than one block, a criterion is required to promote bidding competition and to guarantee the opportunity to switch between blocks at the same time. When applying to the auction, each operator should disclose the maximum bandwidth it hopes to win. And the activity rule forces each bidder to bid at least 50% of the maximum bandwidth. Other rules in standard SMRA, such as eligibility point, are not introduced.

Like in 2013 auction, maximum bid requirement is also adopted to prevent strategic incentive when switching auction format from SMRA to the sealed-bid. But the details of maximum bid is slightly different in that each operator should follow the order of preference in SMRA to bid in sealed-bid auction. That is, if one bidder bids aggressively in a block in SMRA, it can also put higher bid in sealed-bid auction. In other words, to bid aggressively in sealed-bid auction, where the final result could be determined, bidder should reveal the preference in SMRA to some degree. Otherwise, it will not be able to win the most preferable block. Therefore, with maximum bid rule, each operator has to bid truthfully at SMRA stage in a certain way.

4.3 Auction result

The auction is concluded in 8 rounds of ascending rounds, lasting only 2 days. The bidding competition occurs only in the D block, resulting in 45% rise over the reserve price, and the other blocks, B, C, and E, were sold at the reserve price.

SK Telecom won the D and E blocks together, bidding 950 and 328 billion KRW respectively. Korea Telecom won the B block at 451.3 billion KRW, and LGU plus won the C block at 381.6 billion KRW. The 700MHz band A block was unsold, since no bidder bids for it.

Table 6. Result of 2016 auction

Block (Band)	Bandwidth	Duration (year)	Reserve Price (KRW)	Winning Bid (KRW)	Winning Bidder
A(700MHz)	40MHz	10	762 B	–	–
B(1.8GHz)	20MHz	10	451.3 B	451.3 B	KT
C(2.1GHz)	20MHz	5	381.6 B	381.6 B	LGU+
D(2.6GHz)	40MHz	10	655.3 B	950 B	SKT
E(2.6GHz)	20MHz	10	327.7 B	327.7 B	SKT
Total	140MHz	–	–	2,110.6 B	–

Source: MSIP(2016b)

Table 7. spectrum holding of MNOs after 2016 auction (unit: MHz)

	SKT	KT	LGU+
800/900MHz	30	30	20
1.8GHz	35	55	20
2.1GHz	40*	40	40*
2.6GHz	60	—	40
Total	165	125	120

* After December 4, 2016

Compared to the two previous auctions, the 2016 auction only needed 8 rounds to be concluded. I think that it is because that many blocks in different band were supplied and operators' preference over spectrum blocks spreads out. Also bidders bid very aggressively in the earlier round to finish the auction early. The reason is that uncertainty prevails when switched to sealed-bid auction with many blocks and spectrum caps to be considered. Learning effect can be another factor. Since operators have experienced over the two previous auctions, they might think that bidding the true value without strategic incentive is the best strategy. If the spectrum demand for some operator was not as urgent as we thought, it could possibly ease the level of competition.

4.4 Evaluation

I believe that each operator acquired spectrum blocks needed in a cost efficient way. From the auction rule and diversified preference, proper level of competition was occurred, and an efficient allocation was achieved by the market mechanism.

Korea Telecom and LGU plus win the block adjacent to the pre-owned spectrum, therefore spectrum efficiency can be maximized. SK Telecom wins both 2.6GHz blocks of 60MHz bandwidth, so the company could have a room to accommodate its traffic, and could utilize both blocks with one equipment at the base station, that could reduce the expense of network deployment. Operators, who fiercely compete for maximum LTE speed so far using CA technologies, will sublimate speed competition and focus on optimal utilization of the network.

For the auctioned spectrum, the MSIP put coverage obligations higher than previous auctions to promote efficient use of the spectrum. Also since many bands, including 1.8GHz, 2.1GHz, and 2.6GHz, are assigned in 2016 auction, investment effect will be higher than before. This will positively affect the handset, device, and equipment industry with network upgrade. Since SK Telecom, the market leading operator, has to construct newly assigned band, 2.6GHz, we can expect huge investment on network. Additionally, we can expect the development of ICT ecosystem with sophisticated network infrastructure.

For 2.1GHz band, many issues have arisen regarding re-assignment and auctioning bandwidth. From the result, three operators will be able to hold the same amount of spectrum in 2.1GHz band. Though SK Telecom and Korea Telecom should use part of 2.1GHz band to provide 3G service, they could switch to LTE when 3G service is terminated.

However, some negative criticisms about spectrum auction are raised. Regarding 700MHz block, some argues that it should not be auctioned because using mobile telecom with Ultra High Definition (UHD) broadcasting and Public Protection and Disaster Relief (PPDR) altogether is not desirable because of interference concern. Also the guard bandwidth between different usage is not sufficient to protect interference. From the auction result, these argument could be valid at least to some degree, but when planning the auction

in advance the MSIP was not able to conclude with certainty to exclude 700MHz from the auction. The regulator wanted to supply all available bands in the auction and let the market decide what and how much they needed. It was believed that each operator should have the opportunity to secure one broadband spectrum block, which requires 700 MHz band to be supplied.

Another criticism is that since all but one block is sold at the reserve price the auction mechanism is not valid. But I cannot agree with the argument. The purpose of the auction is to determine who gets what and at how much. Therefore, we believe that market mechanism works well to determine the allocation and the price at the same time. The diversified preference over the auctioned spectrum may lead 3 blocks being sold at reserve price, but it does not mean that price competition itself is meaningless.

5. Discussion

The ultimate goal of spectrum policy is to use the spectrum efficiently and hence to promote social welfare. To achieve this, spectrum auction is legislated into the Radio Waves Act and implemented to assign mobile spectrum. By implementing three spectrum auctions in Korea, it is believed that the policy goals were successfully achieved. Not only timely assignment of spectrum made it possible to enhance LTE service, but also regulatory conditions given guaranteed fair competition in mobile market. From the network deployment and technological advances, Korean mobile market and its related areas have competitive edge over global competitors. I believe this trend will continue to 5th generation mobile services, since Korean mobile operators plan to upgrade LTE service to LTE-A Pro in 2018 with 1Gbps of maximum transmission speed. For each auction, there were many issues to be resolved. For some, regulatory condition had to be imposed, but for others, the auction design was able to solve them by market mechanism. I believe that auction as a spectrum assigning mechanism has been working impeccably in Korea.

Table 8. Comparison of Korean 2011, 2013, 2016 auction result

Auction	Band (Bandwidth)	Total Bandwidth	Duration (year)	Reserve price (KRW)	Winning bid (KRW)	Total price (KRW)
2011	800MHz (10MHz)	50MHz	10	261 B	261 B	1,701.5 B
	1.8GHz (20MHz)			445.5 B	995 B	
	2.1GHz (20MHz)			445.5 B	445.5 B	
2013	2.6GHz (40MHz)	90MHz	8	478.8 B	478.8 B	2,428.8 B
	1.8GHz (35MHz)			673.8 B	1,050 B	
	1.8GHz (15MHz)			288.8 B	900 B	
2016	1.8GHz (20MHz)	100MHz	10	451.3 B	451.3 B	2,110.6 B
	2.1GHz (20MHz)		5	381.6 B	381.6 B	
	2.6GHz (40MHz)		10	655.3 B	950 B	
	2.6GHz (20MHz)		10	327.7 B	327.7 B	

However, there are challenges remaining in the upcoming auction. As spectrum assignment by auction continues in every 2 or 3 years, operator's burden on spectrum fee will continue to be aggravated. Therefore, we need to contemplate over the proper value of the spectrum in the future. It will be an important issue, since much wider bandwidth, such as 100MHz per operator in 3.5GHz band and/or 1GHz per operator in 5G band,

will possibly be assigned. Also another concern is that as more spectrum bands are secured for mobile purposes the spectrum demand may not be higher than its supply. In that case, we can question whether spectrum auction is a proper way to assign, and how to run spectrum auction if necessary. There may be other issues to be raised, but including ones mentioned above we have time to prepare and modify the rules to cope with market environment. With proper revisions made, I believe that spectrum auction can be a sustainable market mechanism to assign spectrum efficiently in the future.

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