Review of 2.1GHz Spectrum Auction in Various Countries

S. Malisuwan, N. Yaowakhan, N. Tiamnara, and N. Suriyakrai
National Broadcasting and Telecommunications Commission, Bangkok, Thailand
Email: {settapong.m, nirachorn.y, noppadol.t, nattakit.s}@ nbtc.go.th

***Abstract*—The objective of this paper is to compare 2.1GHz spectrum auction in various countries with emphasis on spectrum packaging, auction format and reserve price. Spectrum packaging which is number of licenses and size of license has direct effects on market competition. For an optimum spectrum packaging an auction designer must consider both market competition, technical requirements and must ensure consistency with auction format. Popular formats for 2.1GHz spectrum auction are sealed-bid, ascending-bid and clock auctions. Furthermore, reserve price is a critical mechanism in controlling competition intensity within the auction, auction revenue and efficient allocation. In this paper, we provide a detailed comparison spectrum packaging, auction format, reserve price, auction procedures and mechanisms used in different countries, to bring clarity on different auction mechanisms that are used to tailor a different outcome.**

***Index Terms*—spectrum, auction, license, reserve price**

I. Introduction

At present, the mobile market in many countries has been developing rapidly. The adoption of mobile service will greatly benefit the economy. Consumers will receive fast and quality telecommunication system and their quality of life will improve. At the same time, the telecommunication infrastructure and industry in Thailand will further develop to meet the new industry standard. Such development will be beneficial to the production of goods and service in the country raising overall competitiveness both domestically and internationally. Basically, telecommunication regulator has the duty to issue the regulation and procedure for spectrum licensing. Such regulation and procedure include setting the reserve price of the spectrum license for use in the auction. The spectrum valuation is an important input for setting a proper reserve price of a spectrum license.

This paper explores the 2.1GHz spectrum auction procedures and formats in various countries with emphasis on spectrum packaging, auction format and reserve price which are important and interrelated issues in auction design. The organization of the paper is as follows. Section II briefly outlines the spectrum packaging. Spectrum auction formats is described in Section III. Reserve price is discussed in Section IV. Auction procedure is explained in Section V. Case studies of spectrum auctions in various countries are in Section VI. Lessons learned from spectrum auction are drawn in Section VII.

Manuscript received January 11, 2015; revised June 20, 2015.

II. Spectrum Packaging

2.1GHz spectrum band consists of paired and unpaired spectrum. There are 2x60MHz paired spectrum, with 1920 to 1980MHz uplink and 2110 to 2170MHz downlink. Spectrum is used in pair. For example, 1920 to 1925MHz is used to send signals from mobile phones to base stations and 2110 to 2115MHz is used to receive signals from base stations. Unpaired spectrum frequency range is 1900 to 1920MHz uplink and 2010 to 2025MHz downlink. For unpaired spectrum, signals are sent and received via the same spectrum with time-division multiplexing. Unpaired spectrum is suitable for unbalanced data transfer. Some countries may deploy 3G service on other bands. For example, US and Canada use AWS and PCS spectrum bands.

Some countries auctioned both paired and unpaired spectrum licenses. Because there was uncertainty about future technology at the time of auction, all spectrums are auctioned so that operators can choose spectrums to maximize their profits. Afterward, it was cleared that paired spectrum is used for 3G technology. Many countries hence auctioned only paired spectrum. Some countries, such as Italy and Switzerland, auctioned the unpaired 2.1GHz spectrum along with other spectrum bands for 4G, but no one bid.

License sizes and the number of licenses are different across countries. License size can range from 2x5MHz to 2x20MHz. License in the same auction may have different size. The numbers of licenses may be different depending on the total bandwidth offered. There may be less than 2x60MHz spectrum available for auction in some countries as some part of the band has been previously allocated.

License sizes and the number of licenses are ones of the most important auction design elements because they dictate the post-auction market structure and competition [1]. An insufficient number of licenses leads to monopolization [2]. If there are too many licenses, operators may not have sufficient spectrum for quality service. Therefore, to choose proper spectrum size and the number of licenses, one must take expected auction

doi: 10.18178/joams.4.6.439-446

outcomes into consideration [2]. There are several choices of license sizes and the number of licenses.

A. Fixed or Flexible Packaging

There are two popular choice of spectrum packaging: fixed or flexible packaging.

1) Fixed packaging

For fixed packaging, license sizes and the number of licenses are determined prior to the auction. An auctioneer must consider several factors such as operators' demand, technical requirements and post-auction competition. Each bidder can win at most one license. Therefore, the number of winners is at most equal to the number of licenses offered. Many countries used fixed packaging for 2.1GHz spectrum auction.

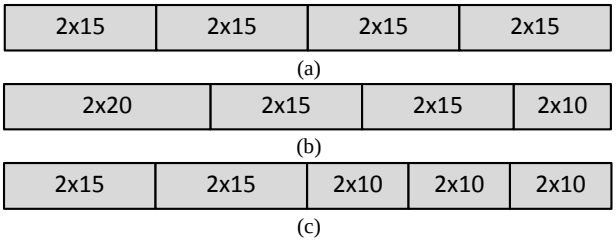

Figure 1. Fixed packaging

If 2x60MHz spectrum is available, there are many possible license sizes and the number of licenses. Fig. 1 shows examples of fixed packaging. In (a), there are at most four winners and each winner receives 2x15MHz. In (b), there are at most four winners as well, but each winner may receive a license with different size. In (c), there are at most five winners with different license sizes.

2) Flexible packaging

For flexible packaging, the license size and the number of licenses are not pre-determined but they are resolved by demand in the auction. In Germany and Austria, 2x60MHz spectrum is divided into 12 lots with 2x5MHz each. As shown in Fig. 2, each bidder can choose his desired license size. For example, a bidder who demands 2x10MHz license can bid on two lots and a bidder who demands 2x15MHz license can bid on three lots.

In an auction with flexible packaging, a spectrum cap must be imposed to prevent any single bidder from anti-competitively obtaining too much spectrum. Germany and Austria imposed a spectrum cap of 2x15MHz. So, each bidder can bid on at most three lots and hence there are at least four licenses if all spectrum is sold.

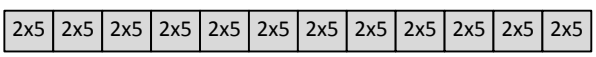

Figure 2. Flexible packaging

The first stage of the auction is to identify winners and their license size but it does not specify frequencies of each license. That is, the license size is 2x10MHz if a bidder won two lots whereas the license size is 2x15MHz if a bidder won three lots. After license sizes have been determined, bidders are allowed to choose specific frequencies. There are many ways to assign frequencies such as random draw and auction. An auction is preferred if different frequency assignments have different values. For instance, some frequency range might have an interference from its adjacent frequency and, as a result, its value is lower than others. If the value of each frequency range is not significantly different, a random draw is simpler and faster.

Normally, a contiguous spectrum for each license is mandated. The one who has the right to choose frequency assignment first cannot select an assignment that prevents other winners from receiving contiguous spectrums. For example, suppose there is 2x60MHz of spectrum for auction. There are four winners of 2x20, 2x15 and 2x10MHz. Possible frequency ranges for the winner of 2x20MHz are shown in Fig. 3. Notice that there is no alternative that makes other licenses non-contiguous.

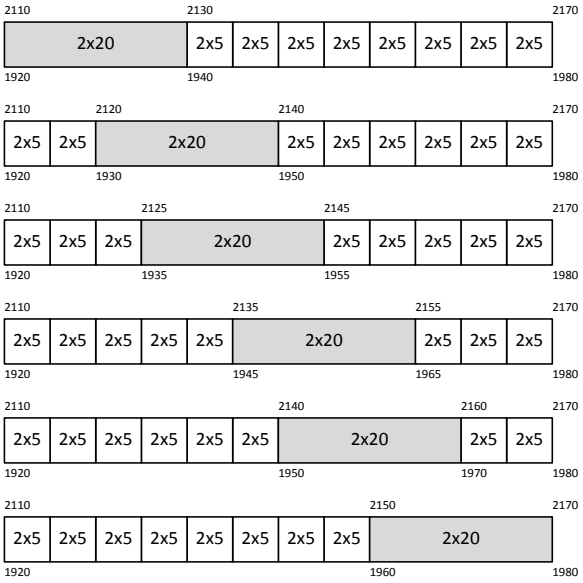

Figure 3. Frequency assignment

One advantage of the fixed packaging is simplicity. It is desirable if an auction designer knows about the optimal license sizes and number of licenses. In contrast, the flexible packaging is preferable if the auction designer does not have a view of the optimal license sizes and number of licenses. The auction designer should then let demand determines the optimal outcome.

B. Nationwide and Regional Licenses

Small countries typically auction nationwide licenses. Some countries with large area or geographical difference such as India, US and Canada usually split each spectrum into smaller regional licenses. However, the number of licenses in each region may be different.

Regional licenses make the auction more complicated because a bidder who demands a nationwide license must aggregate a number of licenses and there is a risk of winning only some part of the nation. Nevertheless, one advantage of regional licenses is to encourage new entrants.

III. Spectrum Auction Formats

There are many popular spectrum auction formats. Auction formats used for 2.1GHz spectrum auctions in other countries are the following.

1. Sealed-bid first-price
2. Simultaneous ascending bid
3. Simultaneous ascending clock

Each auction format works as follows.

A. Sealed-bid First-price Auction

The sealed-bid first-price auction has been used only a few times for spectrum allocation because the allocation may be inefficient. Its advantages are that it is fast and simple, and that it encourages new entrants. Denmark and Indonesia used the sealed-bid first-price auction in their 2.1GHz spectrum auctions.

The sealed-bid first-price auction works as follows. Each bidder submits a bid in a sealed envelope. The auctioneer collects and opens all envelopes. The bidder who submits the highest bid receives the license and pays his bid. If there are N licenses, the bidders who submit N highest bids win the licenses and pay the N-th highest bid. In some case, the auctioneer may set the payment equal to N+1-th bid.

An example of the sealed-bid first-price auction is the following. Suppose there are five bidders competing for four licenses. Their bids are shown in Table I. The winners are four highest bidders: bidder A, B, C and D. The license price is equal to the fourth highest bid, or 200.

TABLE I. Example of Sealed-Bid Auction

Bidder	Bid	Result
A	500	Win
B	400	Win
C	300	Win
D	200	Win
E	100	Lose

B. Simultaneous Ascending Bid Auction

The simultaneous ascending bid auction is the most popular spectrum auction format, not specific to only 2.1GHz spectrum because of its simplicity and efficiency.

The simultaneous ascending bid auction works as follow. All licenses are auctioned and closed simultaneously. Bidders submit bid in rounds. In each round, each bidder can bid on any license but his bid is at least equal to the current round price. A round price is typically equal to the highest bid plus a bid increment. The bid increment may be a proportion of the highest price or reserve price. In some auctions, bid increments are increasing in excess demand.

In the first round, each bid must be at least equal to the reserve price. A bidder who holds the highest bid cannot bid for any other license until another bidder submits a higher bid. The auction ends when no bidder submits any bid. The winners are the highest bidders in the final round and each winner pays his bid.

Normally, this auction format requires bidders to submit a new bid or hold the highest bid in every round to preserve eligibility to bid in the subsequent rounds. A bidder is out of the auction if a bidder is not active in any round. This activity rule is consistent with Law of Demand–as price increases, demand decreases. A bidder can use a waiver if he has some difficulty in bid submission. A bidder who uses a waiver will not lose his eligibility in the subsequent round. Each bidder has a limited number of waivers.

TABLE II. Example of Simultaneous Ascending Bid Auction

Round	Highest bid at the beginning of round			Bid		
	License A	License B	License C	License A	License B	License C
1	-	-	-	A bids 100	B bids 100	C bids 100 D bids 120
2	100 (A)	100 (B)	120 (D)	-	C bids 120	-
3	100 (A)	120 (C)	120 (D)	B bids 120	-	-
4	120 (B)	120 (C)	120 (D)	-	-	-

An example of the simultaneous ascending bid auction is the following. Suppose there are four bidders, A, B, C and D, and three licenses, A, B and C. The reserve price for each license is 100. As show in Table II, there is no highest bidder in the first round. Bidder A bids on license A at 100. Bidder B bids on licenses B at 100. Bidder C and D bid on license C at 100 and 120, respectively. As a result, bidder A and B are the highest bidders on license A and B at 100 and bidder D is the highest bidder on license C at 120. If there is no new bid submitted in the next round, the highest bidders in the previous rounds win.

In the next round, bidder C bids license B at 120. He is then the highest bidder instead of bidder B and the auction proceeds. In the third round, bidder B bids license A at 120 topping bidder A. In the fourth round, no bidders bid. The auction ends and each of bidder B, C and D receive a license at 120.

This auction format is applicable to the flexible packaging as well. In Germany and Austria spectrum auctions, each bidder may bid for two or three lots in each round. In the first round, each bidder can bid either two or three lots. If a bidder bids two lots in any round, he cannot bid three lots in the subsequent rounds. A bidder who does not bid on any lot is ineligible to bid again. The auction ends when no bidders submit any bid. Similar to an auction with fixed packaging, the activity rule is consistent with Law of Demand.

C. Simultaneous Ascending Clock Auction

The simultaneous ascending clock auction is not widely used for 2.1GHz spectrum but this auction format is highly efficient as the simultaneous ascending bid auction. India uses the simultaneous ascending clock auction to allocate 2.1GHz spectrum.

The simultaneous ascending clock auction works as follows. All licenses are auctioned and close simultaneously. In each round, a price is announced. Each bidder submits his demand at the current price. If there is excess demand, the auction proceeds to the next round and the next round price increases by one bid increment. Each bidder must submit his demand at the next round price. The auction ends when there is no excess demand. In each round, each bidder's demand must remain the same or decrease, consistent with Law of Demand.

An example of the simultaneous clock auction is shown in Table III. There are four bidders A, B, C and D competing for two licenses. In the first round, the auctioneer announces a price of 100. Each bidder must submit his demand of zero or one. All bidders submit demand of one at the price of 100 baht. Therefore, the excess demand is equal to two. The auction proceeds to the next round. In the second round, the auctioneer announces a price of 120. All bidders submit demand of one except bidder C who submits demand of zero. Hence, bidder C is out. The excess demand in this round decreases to one. In the third round, the price increases to 140. No bidder reduces demand and thus the excess demand remains the same. The auction then proceeds to the fourth round. This round price is equal to 160. Bidder D reduces his demand to zero. Thus, there is no excess demand. The auction ends and bidder A and B receive the licenses at a price of 160.

TABLE III. EXAMPLE OF SIMULTANEOUS ASCENDING CLOCK AUCTION

Round	Price	Demand (Bidders)				Excess demand
		A	B	C	D	
1	100	1	1	1	1	2
2	120	1	1	0	1	1
3	140	1	1	-	1	1
4	160	1	1	-	0	0

IV. RESERVE PRICE

Unlike choosing an auction format, there is no principle about the choice of reserve price. In addition to spectrum value, one must consider other factors when setting a reserve price. Too low reserve price may lead to revenue loss if there is no competition in the auction. Too high reserve price may create a barrier to entry and some spectrum may be unsold leading to an inefficient allocation.

Moreover, the reserve price also affects the incentive to collude–bidders agree not to complete in the auction to keep the price as low as the reserve price [2]. The payoff from collusion is large if the reserve price is small. So, setting a higher reserve price will discourage collusion.

The reserve price is the lowest possible price. If the auction is competitive, the final price will be higher than the reserve price. If there is no competition, the final price may be equal to the reserve price. Fig. 4 shows the reserve and final prices of 2.1GHz spectrum auctions in various countries. In Germany and UK, the final price is higher than the reserve price although the reserve price is low. In other countries such as Singapore and Greece in which there is no competition in the auction, the final prices are equal to the reserve prices.

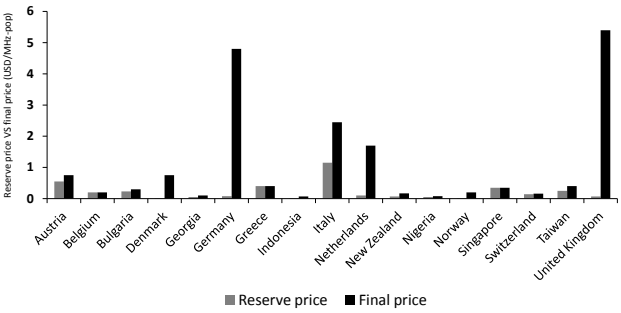

Figure 4. Reserve prices in 2.1GHz spectrum auctions in various countries

V. AUCTION PROCEDURE

In most countries, an information memorandum which lays out details of, for example, applications process, applicant requirements, available licenses, auction rules, payment rule and licensee requirements, is released first. There may be more than one information memorandum. The auctioneer will release a draft of information memorandum for public consultation first. After gathering public opinions and revising the information memorandum, the final version is published. Some countries may conduct more than one public consultation.

The auction procedure starts after the final information memorandum is released. The auction procedure is divided into four steps: application process, qualification process, auction process and licensing process. Each step takes different amounts of time. The outline of each step is the following.

A. Application Process

After the final information memorandum is released, interested parties can submit applications by the deadline. Each interested party must submit an application form, certificate of qualification and other documents as well as application fee and deposit. The deposit can be set as, for instance, a proportion of the reserve price of a license or the largest allowable size if the flexible packaging is used.

B. Qualification Process

After receiving application, the auctioneer will verify applications and documents, and check applicant qualifications. For instance, an applicant must possess a telecommunication service provider license, the authorized capital must exceed the maximum requirement and the applicant's shares of other bidders must be less than a certain level. If any bidder fails to meet the requirements, the auctioneer may ask the bidder to make an amendment or reject his application.

C. Auction Process

There are many auction formats as mentioned above. An auction may be short or long depending on the auction format and the level of competition. The simultaneous ascending bid or clock auction usually takes longer that the sealed-bid auction. The simultaneous ascending bid will even take longer if there is a strong competition.

Normally, bidding can be done via the internet. A bidder may access the auction system from his office. In some countries, bids can submitted via fax whereas in other countries, the auction takes place at the auctioneer's office.

D. Licensing Process

After winners are determined in the auction process, the winners must make payments as indicated in the auction rule. The auctioneer may allow installments. However, the winner must pay some portion of the payment right after the auction and make the remaining payments afterward. Then, the spectrum licenses are granted to winners who meet all requirements and make the mandatory payments.

VI. Spectrum Auctions in Various Countries

TABLE IV. 2.1 GHZ SPECTRUM AUCTION FORMATS IN OTHER COUNTRIES

Country	Auction format	
	Paired spectrum licenses	Reserve price (USD/MHz/pop)
United Kingdoms	Simultaneous ascending bid auction	
	Two 2x15MHz licenses Three 2x10MHz licenses	0.09
Netherlands	Simultaneous ascending bid auction	
	Two 2x15MHz licenses Three 2x10MHz licenses	0.09
Germany	Simultaneous ascending bid auction	
	Unspecified license size 12 lots of 2x5MHz	0.06
Italy	Simultaneous ascending bid auction	
	Two 2x15MHz licenses Three 2x10MHz licenses	1.12
Switzerland	Simultaneous ascending bid auction	
	Four 2x15MHz licenses	0.12
Austria	Simultaneous ascending bid auction	
	Unspecified license size 12 lots of 2x5MHz	0.51
New Zealand	Simultaneous ascending bid auction	
	One 2x15MHz license Three 2x10MHz licenses	0.04
Singapore	Simultaneous ascending bid auction	
	Four 2x15MHz licenses	0.39
Greece	Simultaneous ascending bid auction	
	One 2x20MHz license Two 2x15MHz licenses One 2x10MHz license	0.38
Denmark	First-price sealed-bid auction	
	Four 2x15MHz licenses	-
Taiwan	Simultaneous ascending bid auction	
	One 2x20MHz license Two 2x15MHz licenses One 2x10MHz license	0.25
Indonesia	First-price sealed-bid auction	
	Three 2x5MHz licenses	-
Nigeria	Simultaneous ascending bid auction	
	Four 2x10MHz licenses	0.03
India	Simultaneous clock auction	
	Three to four 2x5MHz Licenses per service area	0.23

Table IV compares 2.1GHz spectrum auction formats in various countries. Notice that most countries used the simultaneous ascending bid auction and that the spectrum packaging and reserve prices vary across countries.

Interesting spectrum auctions in other countries are discussed below.

A. United Kingdoms

The United Kingdoms is the first country that auctioned 2.1GHz spectrum [2]. The auction has been regarded as one of the most successful auctions in terms of market competition and auction revenue. There are five licenses offered as shown in Table V.

TABLE V. LICENSES IN UK SPECTRUM AUCTION

License	Spectrums (MHz)		Prices (million pounds)	
	Paired	Unpaired	Reserve	Final
A	2x15	5	125	4,385
B	2x15	0	107.1	5,967
C	2x10	5	89.3	4,003
D	2x10	5	89.3	4,004
E	2x10	5	89.3	4,095

Each license consists of both paired and unpaired spectrum. License A is set-aside for new entrants. Incumbents can bid for only license B to E whereas new entrants can bid on any license. The license length is 20 years. Each bidder can bid on only one license and the auction format is the simultaneous ascending bid auction.

Four incumbents and nine new entrants participated in the auction. The auction took 150 rounds or almost two months because of the strong competition. The auction revenue was as high as 22.5 billion pounds. The final prices were different across licenses even though the licenses are identical (license C to E). License A was cheaper than the others since it was set-aside for new entrants. However, the competition on license A spilled over to other licenses raising their prices.

In addition to the set-aside license, a factor that made license prices very high was the bubble in technology stocks. The stock prices in telecommunication sector had made the all-time high. If an operator had not received a license, its stock price may have sharply dropped. Furthermore, it was the first auction in Europe. Receiving the license enabled a smooth access to other European markets.

B. Netherlands

The Netherlands is the second country that auctioned 2.1GHz spectrum [3]. The spectrum packaging and auction format are similar to UK. There are five licenses as shown in Table VI.

TABLE VI. LICENSES IN NETHERLANDS SPECTRUM AUCTION

License	Spectrums (MHz)		Prices (million pounds)	
	Paired	Unpaired	Reserve	Final
A	2x15	5	100	1,703
B	2x15	5	100	1,697
C	2x10	5	90	1,045
D	2x10	5	90	1,042
E	2x10	5	90	955

An important difference between the auctions in Netherlands and UK is their reserve prices. In Netherlands, the reserve price decreases if no bidder bids at the reserve price. The reserve prices for license A and B will decrease to 90 million guilders if there is no bid in the first round. If there is still no bid in the subsequent rounds, the reserve price will decrease to 35 million guilders and then zero guilder. For license C, D and E, the reserve price will decrease to 60, 30 and 0 million guilders, respectively. Each bidder has three waivers.

In the first three rounds, all bidders except one use waivers to drive the reserve prices to zero and started bidding seriously afterward. Near the end of the auction, one bidder sent a letter to one small bidder threatening to initiate a lawsuit because he thought the small bidder bid just to push the price up to increase cost of other bidders without any intention to win. Although the small bidder filed a complaint to the auctioneer, the auctioneer took no action because a disqualification of the threatening bidder was expected to cause a serious damage to the post-auction competition. Thus, the auction needed to proceed and the small bidder was eventually dropped out. In the end, the auction revenue was less than the government expected.

C. Italy

The Italy auction format is similar to that of UK [4]. A major difference is the former requires that the number of licenses must be fewer than the number of bidders by at least one. The objective of this rule is to increase competition and revenue. Since there were six bidders, all five licenses were auctioned. However, the new entrant quitted in late than two days after the auction started. One government official revealed that a nominee was set up to make all licenses available for auction. In the end, there was no lawsuit because there were inadequate evidences. The policy to hold off a license was criticized because it reduces the post-auction competition just to make the auction look better.

D. Switzerland

In Switzerland, there are four licenses of 2x15MHz and the auction format is simultaneous ascending bid auction [4]. However, the reserve price is low relative to Switzerland's GDP per capita. A total of 10 incumbents and new entrants qualified. However, there were four bidders left when the auction was about to start. The Federal Office of Communication thus postponed the auction in attempt to change the auction rule but the bidders threatened to file a lawsuit. There was no change in the rule in the end. As a result, there was no competition in the auction and the auction ended at the reserve price which is relative low. However, a new entrant successfully gained access to the market.

E. Germany and Austria

In Germany auction, the flexible packaging and simultaneous ascending bid auction were used [4]. Each bidder can bid for two or three lots. Thus, the number of licenses can range from four to six. Initially, there were 12 applicants but five of them withdrawn before the auction started. At the end, seven bidders, four of which were incumbents, participated. The auction took over two weeks because of strong competition. The auction ended at around 173. The revenue was very high and the six winners were four incumbents and two new entrants. Each of them received 2x10MHz license. It notes that during the auction, bidders sent signals to each other with the final digit of their bids to lessen competition. In round 130 to 150, one bidder submitted bids ending with "6" to communicate to other bidders that he wants the auction to end with six winners. The auction eventually ended with six winners.

The Austria auction format is the same as Germany auction but there were only six bidders. The auction was not competitive because each bidder reduced his demand to 2x10MHz around the beginning of the auction to keep license prices low. If any bidder had bid 2x15MHz, the auction would have had excess demand and bidders would have competed until that bidder reduced his demand. The auction ended around the reserve prices. There was a rumor that competition at the beginning of the auction was staged to mislead the government and the public and to lower the risk that the government cancels the auction.

F. Belgium and Greece

Belgium and Greece auctioned four 2x15MHz licenses with simultaneous ascending bid auctions [2]. In Belgium, three incumbents and no new entrant participated because the incumbents' market shares were as high as two third. In Greece, three incumbents participated as well because its income per capita was low. There was no excess demand in the auction and the auction ended at the reserve price.

G. Denmark

Denmark auctioned four 2x15MHz licenses with a sealed-bid auction in which the final price equal to the fourth highest bid [2]. Five bidders participated. The use of the sealed-bid auction increases a new entrant's chance of winning and encourages incumbents to bid more aggressively to lower the risk of losing. As a result, the final price was twice as high as expected and the new entrant successfully gained access to the market.

H. Singapore

Singapore auctioned four 2x15MHz licenses with a simultaneous ascending bid auction. There were four participants but only three bidders made deposits. The three bidders were awarded the licenses at the reserve price without having a bid.

I. India

Since India has a larger area than many other countries and there were several regional operators, each spectrum is divided into smaller licenses for 22 service areas (circle). There were three to four licenses in each service area. A service area with high population density or an urban area covers a small region whereas a rural service area covers a

large region. Each bidder can bid for only one license in each region but he can bid on any region. Licenses in each service area are shown in Table VII.

TABLE VII. LICENSES IN INDIA 2.1 GHZ SPECTRUM AUCTION

Service area	Number of licenses	Prices (million rupees)	
		Reserve	Final
A(Metro) - Delhi	3	320	3,317
A(Metro) - Mumbai	3	320	3,247
A - Maharashtra	3	320	1,258
A - Gujarat	3	320	1,076
A - Andhra Pradesh	3	320	1,373
A - Karnataka	3	320	1,580
A - Tamil Nadu	3	320	1,465
B(Metro) - Kolkata	3	120	544
B - Kerala	3	120	312
B - Punjab	4	120	322
B - Haryana	3	120	223
B - Uttar Pradesh (E)	3	120	365
B - Uttar Pradesh (W)	3	120	514
B - Rajasthan	3	120	321
B - Madhya Pradesh	3	120	258
B - West Bengal	4	120	124
C - Himachal Pradesh	4	30	37
C - Bihar	4	30	203
C - Orissa	3	30	97
C - Assam	3	30	41
C - North East	3	30	42
C - Jammu & Kashmir	3	30	30

The auction format is the simultaneous clock auction. Seven bidders participated. The auction took roughly one month or 183 rounds because the auction was highly competitive and the auction was designed to maximize revenue while sacrificing efficiency. As a result, the final prices were significantly higher than the reserve price, especially for the licenses covering urban areas [5].

J. Thailand

In the 2012 auction, the first spectrum auction in Thailand, the regulator designed the auction of 2x45MHz spectrum, each having the standard minimum amount of 2x5MHz with the aim of allowing bidders to determine their desired amount of spectrum pursuant to market forces [6]. The 2x5MHz block size was also intended to encourage competition by making it more feasible for new entrants and smaller operators to gain a foothold in the market. The new licenses were required to provide telecommunications network service with the minimum capacity of 10% of their networks to mobile virtual network operators (MVNOs), when receiving such service request. The Thai regulator provided this in order to ensure that there would be significant retail level competition, thereby benefiting consumers. Although there is much to be said for not burdening investors rolling out new infrastructure with obligations to carry their competitors on their network capacity, there is no evidence that this reduced bidder interest in the licenses.

The auction followed the simultaneous multiple round (SMR) method of bidding, which involves bidders bidding at the same time but with bids submitted in rounds, between which bidders may consider and change their bidding strategy, giving them greater control over their own choices. The auction set a reserve price at 70% of the market value as calculated by Chulalongkorn University. The University had recommended a reserve price of at least 67%. This is not an unusual level to set a reserve price. Indeed, reserve prices are often set well below the estimated value [7].

VII. LESSONS LEARNED FROM SPECTRUM AUCTIONS

Since 2000, many countries have allocated 2.1GHz spectrum with the auction. UK was the first to auction 2.1GHz spectrum using a simultaneous ascending bid auction. The UK auction has been regarded as a successful auction in terms of competition in the market and revenue. However, many countries that followed UK auction design were not as successful as expected. Apparently, the auction format that is suitable for one country might not fit others. To choose an auction format which can best achieve auction objectives, an auction designer must consider the context of the country. One should learn the failures of auctions in other countries as case studies for auction design in Thailand.

The spectrum packaging is an important determinant of competition in the market. Operators may not have sufficient spectrum if licenses are too small. However, the competition in the market is weak if there are too few licenses. If it is not obvious how large and how many licenses should be auctioned, an auction designer can use the flexible packaging as in Germany or Austria auctions. In this case, a spectrum cap should be imposed to prevent one bidder from winning too many spectrums.

The reserve prices are non-trivial if the auction is uncompetitive. However, the auctioneer may not know whether the auction is competitive before the actual auction takes place. The reserve price is similar to price guarantees for licenses in case there is no competition. In Switzerland, the auction was seemingly competitive at first but, in the end, bidders used business strategies such as forming a coalition to reduce competition making the auction end at the reserve price. Therefore, a proper reserve price would have prevented the low revenue in this case. Another lesson learned from Belgium auction is that the auction designer should not allow the reserve price to decrease if there is no demand and give waivers to bidders at the same time because bidders can use all waivers to lower the reserve prices and then start bidding seriously afterward.

In addition to the auction design issues, the auctioneer must consider uncontrollable factors. An efficient auction and auction rules that encourage new entrants may not be fruitful if external environment is not suitable for new entrants. As in Greece and Belgium auctions, there were licenses left unsold. The auction is merely one step of spectrum allocation and whether it can achieve objectives

depends on many other factors such as market condition, economy, politics, regulation, laws and so on. However, the auction rules are the more controllable than others. Hence, a good auction design will be an important step in allocating spectrum efficiently. Such efficiency in turn strengthens the competition in the market and the consumers will eventually benefit from the competition in terms of lower price, better service quality and innovations.

VIII. Conclusion

Spectrum auction serves as a critical gateway to deliver a quality mobile telecommunication system, essential for overall development of a country. The ambitions are to provide sufficient spectrum and robust competition among operators while securing an optimal revenue for the country. Drawing from the lessons learned around the world, the process of spectrum packaging, reserve price setting and auction designing cannot be complete without carefully taking the current situations and aspirations of the local industry into account. Global experiences in combination with deep local understanding will be the key to success.

References

[1] P. Cramton, "Lessons learned from the UK 3G spectrum auction," University of Maryland, Department of Economics, 2001.

[2] P. Klemperer, "How (not) to run auctions: The European 3G telecom auctions," *European Economic Review*, vol. 46, pp. 829-845, 2002.

[3] E. V. Damme, "The Dutch UMTS-auction," Tilburg University, Center for Economic Research, 2002.

[4] V. Grimm, F. Riedel, and E. Wolfstetter, "The third generation (UMTS) spectrum auction in Germany," 2001.

[5] P. Cramton and P. Sujarittanonta, "Pricing rule in a clock auction," *Decision Analysis*, vol. 7, pp. 40-57, 2010.

[6] J. Restrepo, R. Macmillan, and A. M. Foster, "ITU: Thailand 3G auction review report," 2013.

[7] W. Paitoon, P. Pongsa, T. Bangorn, C. Charuwan, P. Tanapong, S. San, *et al.*, "Spectrum valuation and reserve price determination of IMT 2.1GHz spectrum licensing," Faculty of Economics Chulalongkorn University, July 2012.

Settapong Malisuwan was born on 24th March 1966 in Bangkok, Thailand. He received his Ph.D. in Electrical Engineering (Telecommunications), specializing in EMI/EMC from Florida Atlantic University (State University System of Florida), Boca Raton in 2000. He received a MS in Electrical Engineering specializing in mobile communications system from The George Washington University in 1996, a MS in Electrical Engineering from Georgia Institute of Technology in 1992, and a BS in Electrical Engineering from Chulachomklao Royal Military Academy, Nakhon-Nayok, Thailand in 1990. He served in the Royal Thai Armed Forces for more than twenty five years. His research interests are in efficient spectrum management and telecommunications policy and management. Col. Dr. Settapong Malisuwan is currently the Elected Vice Chairman and Board Member in the National Broadcasting and Telecommunications Commission, Thailand.

Nirachorn Yaowakhan was born on 19th October 1975 in Bangkok, Thailand, received her Master of Science in Telecommunications from University of Colorado at Boulder in 1998 and B.Eng (Electrical Engineering) from Chulalongkorn University in 1996. Since joining mobile telecommunications industry in 1999, she has worked on various projects within APAC, starting from solution engineering and greenfield rollout to network modernization and new technology introduction. In her current position as an Assistant to Secretary of Vice Chairman of National Broadcasting and Telecommunications Commission (NBTC), her research interests span over spectrum management, alternative spectrum licensing approaches, and application of mobile technology for public protection and disaster relief.

Noppadol Tiamnara was born on 12th November 1968 in Prah Na Korn Sri Ayutthaya, Thailand. He received his M.S. in Technology Management from Thammasat University, Thailand in 2012, a B.Eng. in Electrical Engineering from Saint John's University, Thailand in 2002, and a Diploma of Vocational Education in Industrial Technology from South-East Asia College, Thailand in 1990. Since 2006, he has been working as an Assistant to Secretary of Vice Chairman of National Broadcasting and Telecommunications Commission (NBTC). His research interests include LTE design, wireless systems, micro-strip antenna, and applied electromagnetic.

Nattakit Suriyakrai was born in Khonkhaen, Thailand on 22nd March 1987. He received his Bachelor of Liberal Arts in Japanese Language from Thammasat University in 2010. He has been working as an Assistant to Vice Chairman of National Broadcasting and Telecommunications Commission (NBTC) in Bangkok, Thailand since November 2012. His research interests are in technology management and spectrum management.