5 Cost Implications

5.1 General

This chapter discusses the cost of mobile communication systems and analyzes from the perspective of several '5G' related use cases. The fundamental cost implications of '5G' were analyzed in [1] where every element of a mobile communication system was analyzed in terms of CAPEX or OPEX. The analyses were made with a focus on the domestic market of Japan, in light of demographic and survey data as well as local market indexes. Since the market in Japan is one of the leading markets in the world, these case studies may be of use when considering markets in other locations around the world.

Section 5.2 presents a case study on communication traffic as it relates to mobile broadband. While existing mobile communication systems such as LTE has already experienced many of the situations discussed, more sophisticated and enriched services including device to device communications are expected in the age of 5G. Section 5.3 discusses scenarios related to coverage in sparsely populated areas. As with communication traffic, considerable efforts have been made up to now and existing mobile communication systems cover more than 99.97% of the total population of Japan. The number of people in Japan that is not covered by current mobile communication systems is estimated to be less than 39 thousand [2]. Accordingly, the expansion of service areas themselves would be about on-going improvement and the task of '5G' in this regard is to be able to provide reasonable services at a reasonable cost even in sparsely populated areas. As in the first use case, devices deployed in sparse manner that provide device to device communications should also be taking into account. Section 5.4 considers the dynamics of communication traffic. The case study presented is the enormous flow of commuters in the mornings and evenings in the context of daytime population density vs. night time population density. The '5G' system needs to be able to cope with a large variation of population density, including a large daily flow of commuters. Since people may carry more mobile devices than ever in the '5G' era, the ratio of daytime and nighttime communication traffic may become larger and the volume of mass communication traffic along commuting routes may rapidly increase, as well.

Since one important framework of '5G' is to be able to cover a variety of use cases in a cost effective manner, a '5G' system should be designed to be as flexible and scalable as possible. Accordingly, in most of the cases (especially use cases specific to '5G'), it would be useful to apply specific technologies, configurations or operating method suitable to these certain use cases and combine these elements into a unified communication system, rather than to seek generic, common and robust technologies covering each and every use cases overall.

5.2 Costs per communication traffic aspect

As described in the previous section, the volume of mobile communication traffic has been increasing rapidly thanks to the expansion of mobile broadband applications. This growth will continue over the next decade. In this section, mobile communication system costs are analyzed in the context of traffic volume versus revenue of the mobile communication operators as well as users' expense.

The charts in Figure 5.2-1 estimate annual traffic volume using data from [3]. Simple linear interpolation is applied to the original estimated mobile communication traffic for every three months' interval and then added up to derive the estimated annual traffic volume. The results, summarized in Figure 5.2-2, show growth in traffic, both overall and on a per subscriber basis traffic (also derived from [3]). As can be seen, overall traffic grew five times between the years of 2011 and 2013 and four times during that same time period on a per subscriber basis.

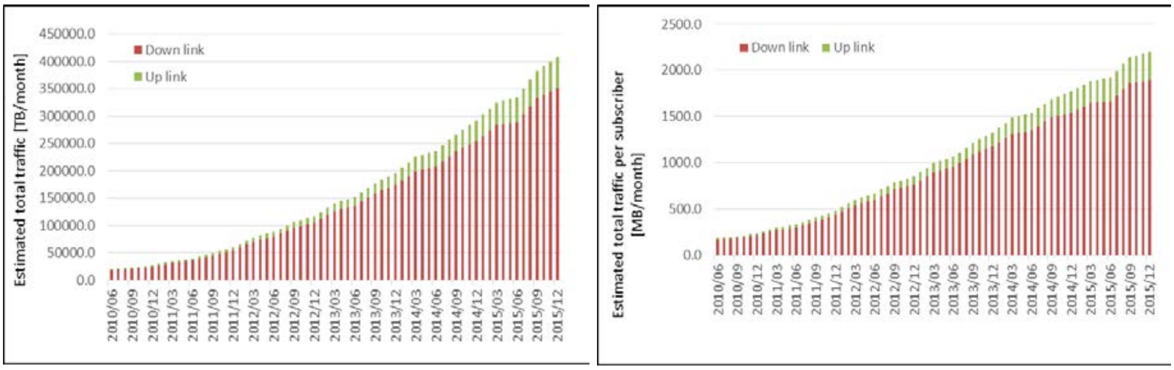

Figure 5.2-1 Estimated communication traffic growth in Japan (Derived from [3])

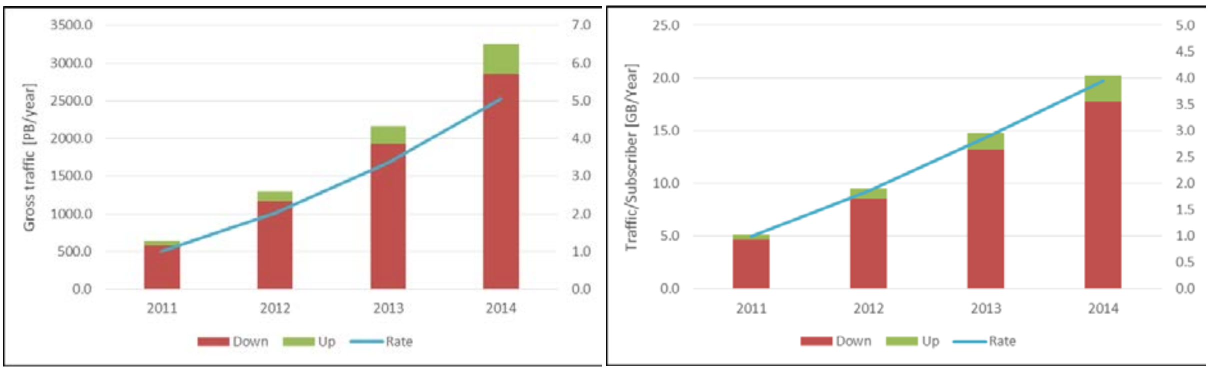

Figure 5.2-2 Estimated communication traffic growth rates in Japan (Derived from [3])

In the meantime, user expenditures are fairly stable as shown in Figure 5.2-3 (Derived from [4]). The total average expenditure of households has been gradually increasing However, rate of increase is around 50% (1.5 times) over the 10-year time frame between 2004 and 2014. Expenditures in one-person households has remained flat at around 4,000 yen over the last decade.

Figure 5.2-4 (Derived from [4]) represents the increasing rate of household expenditures for mobile communication services from 2011 to 2014. The rate increased about 10% over this period. Compared to growth of traffic over the same of the same period, which was four times per subscriber, the increase in the rate of the expenditure could be considered rather modest.

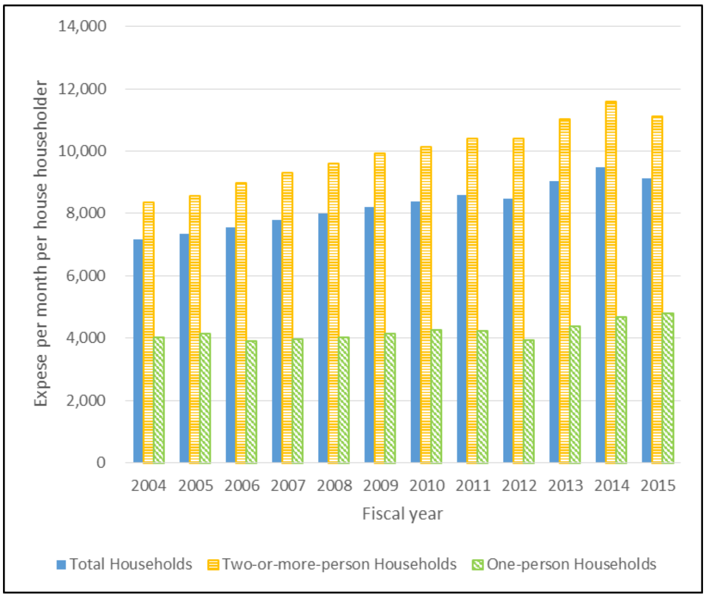

Figure 5.2-3 Householders expenditure for mobile communication services (Derived from [4])

Figure 5.2-4 Relative Householders expenditure for mobile communication services (2011 = 1.0) (Derived from [4])

As a counterpoint to households' expenditures, Figure 5.2-5 (Derived from [5]) represents the total sales of mobile communication operators in Japan. While revenue from data communications services largely increased by a factor of two, income from voice services declined, keeping overall sales revenue constant.

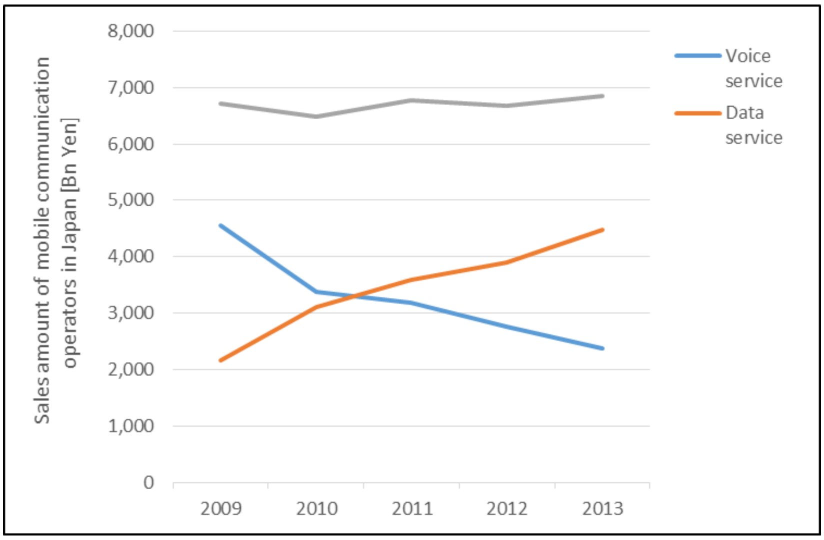

Figure 5.2-5 Sales amount of mobile communication operators in Japan (Derived from [5])

In conclusion, it can be observed that the increase in data traffic in mobile communication services has not contributed to the income of mobile communications operators'. While the increase in communication traffic will continue for the next decade, there is an upper boundary of the capacity for mobile communication systems due to the physical upper limit of communication resources (such as frequency spectrum, frequency efficiency of the radio access technologies etc.). Accordingly, one of the fundamental factors of '5G' will be to provide wider bandwidth services utilizing wider frequency spectrum, for example, without any with only a reasonable cost increase, at most, compared to the new value provided by it.

5.3 User density perspective

This section describes the effects density has on the cost of mobile communication systems. As has been analyzed for optical fiber communication lines and mobile communication networks in [6] and [7], the average cost per individual contract increases as user density is decreases (see Figure 5.3-1 and Figure 5.3-2).

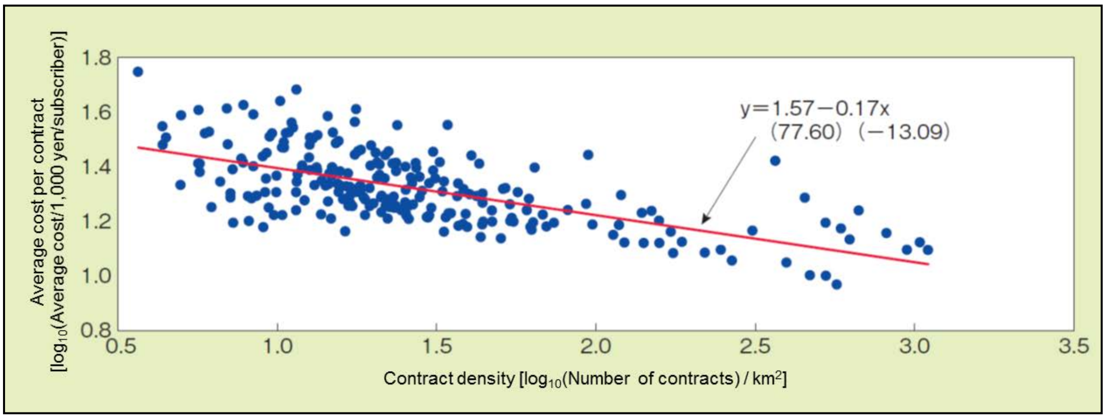

Figure 5.3-1 Contract density and cost of optical fiber networks (English translation of [6])

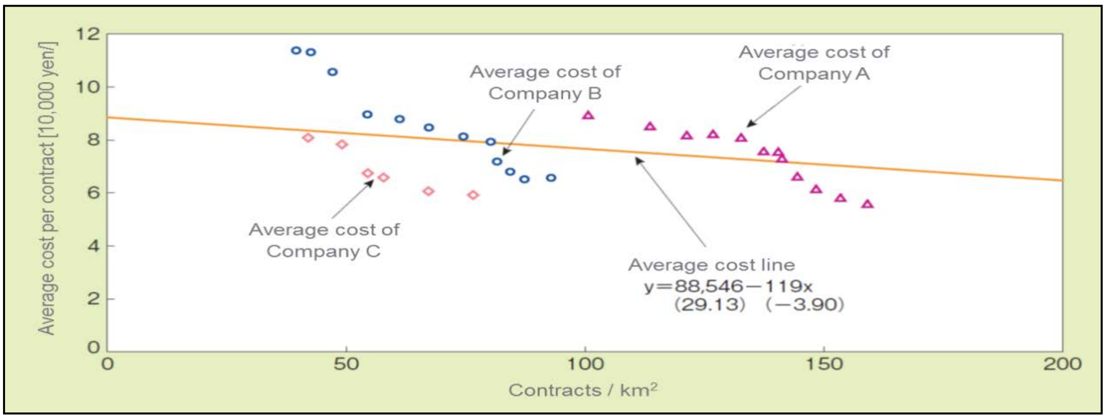

Figure 5.3-2 User density and cost of mobile communication networks (English translation of [6], Summary in English in [7])

In the charts below, approximated costs are expressed by the following equations:

For the average cost per contract of optical fiber lines;

.(1)

Where represents common logarithm of the average cost (unit in 1,000 yen) divided by number of the contracts in question and represents common logarithm of number of contracts divided by the area (unit in square kilo meter).

For the average cost per contract of mobile communication networks;

.(2)

Where represents the average cost (unit in 10,000 yen) divided by number of the contracts in question and represents density of the contracts (unit in per square kilometer).

This can be shown by using the population density of Japan, which is expected to reflect the density of the contractor or subscribers discussed above. To understand the dynamics in daytime and nighttime, two types of demographical statistics i.e. daytime populations and nighttime populations, are used.

Table 5.3-1 (Derived from [8] and [9]) shows the classification of municipal governments within Japan. According to statistics given in [9], there are 1892 municipal governments in the nation as of 2015. In terms of population, municipalities span a few hundred people to several hundred thousand people. In terms of size, the smallest municipality has an area of less than five square kilometers while the largest ones can have an area of more than two thousand square kilometers. This wide range of populations and sizes affects deployments cost as well as operational costs of the communication systems.

Table 5.3-1 Classification of local governments in Japan (Derived from [8] and [9])

Population range (p: Poplulation per local government)	Number of local governments	Gross						Average (per local government)					Population density	
		(a) Area [km^2]	Population				(a') Area [km^2]	Population					
			(b) Daytime	(c) Night time	(d) Delta = (a) - (b)	(e) Daytime / Night time = (a) / (b)		(b') Daytime	(c') Night time	(d) Delta = (a') - (b')	(e) Daytime / Night time = (a') / (b')	(f) Daytime = (b) / (a)	(g) Night time = (c) / (a)
p ≥ 500,000	20	3,060.9	12,513,780	9,985,144	2,528,636	125.3%	153.0	625,689	499,257	126,432	125.3%	4,088.3	3,262.2
500,000> p ≥ 300,000	58	18,144.2	22,147,083	21,337,950	809,133	103.8%	312.8	381,846	367,896	13,951	103.8%	1,220.6	1,176.0
300,000> p ≥ 200,000	74	14,463.4	18,347,162	17,465,208	881,954	105.0%	195.5	247,935	236,016	11,918	105.0%	1,268.5	1,207.5
200,000> p ≥ 100,000	243	44,083.0	34,390,935	36,099,366	-1,708,431	95.3%	181.4	141,526	148,557	-7,031	95.3%	780.1	818.9
100,000> p ≥ 50,000	284	61,282.0	19,986,351	21,163,849	-1,177,498	94.4%	215.8	70,374	74,521	-4,146	94.4%	326.1	345.4
50,000> p ≥ 30,000	246	54,540.7	9,591,857	10,156,000	-564,143	94.4%	221.7	38,991	41,285	-2,293	94.4%	175.9	186.2
30,000> p ≥ 10,000	468	82,976.5	8,562,351	9,173,970	-611,619	93.3%	177.3	18,296	19,603	-1,307	93.3%	103.2	110.6
10,000> p	499	94,399.7	2,517,833	2,675,865	-158,032	94.1%	189.2	5,046	5,362	-317	94.1%	26.7	28.3
Total	1892	372,950.4	128,057,352	128,057,352	0	100.0%	197.1	67,684	67,684	0	100.0%	343.4	343.4

Table 5.3-2 and Table 5.3-3 resorts the municipal governments in Table 5.3-1 in terms of daytime population and area and daytime population density and area respectively. Figure 5.3-3 and Figure 5.3-4 is a three dimensional visualization of the previous tables. It can be observed that the mode of the counts in the daytime population (Table 5.3-2 and Figure 5.3-3) is found at population range less than 10,000 and the area of the organizations are between 200 and 500 km^2. It can be inferred from this that a considerable number of relatively wide and sparse local municipalities in rural areas are dominant in terms of the counts of these organizations. Looking at the daytime population density in Table 5.3-3 and Figure 5.3-4, the number of densely populated municipalities with relatively small sizes becomes visible. These wards (Ku) or cities (Shi) form densely populated metropolises. It should also not be overlooked that the mode is still located at sparsely populated yet relatively large municipalities which have a population density of less than 50 people per square kilometers.

Table 5.3-2 Counts of local governments in Japan (Area vs. Day time population) (Derived from [8] and [9])

Area ＼ Population	10,000> P	30,000> P ≥ 10,000	50,000> P ≥ 30,000	100,000> P ≥ 50,000	200,000> P ≥ 100,000	300,000> P ≥ 200,000	500,000> P ≥ 300,000	P ≥ 500,000	Total
A ≥ 1,000	5	5	3	6	5	1	2	0	27
1,000> A ≥ 500	38	30	24	32	27	9	11	2	173
500> A ≥ 200	123	104	72	59	34	11	18	3	424
200> A ≥ 100	111	99	55	46	31	8	5	1	356
100> A ≥ 50	103	85	38	53	31	13	8	5	336
50> A ≥ 20	75	90	33	38	58	22	10	5	331
20> A ≥ 10	25	35	18	33	44	9	3	4	171
10> A	19	20	3	17	13	1	1	0	74
Total	499	468	246	284	243	74	58	20	1892
							(A: Area in km^2, P: Daytime Population)		

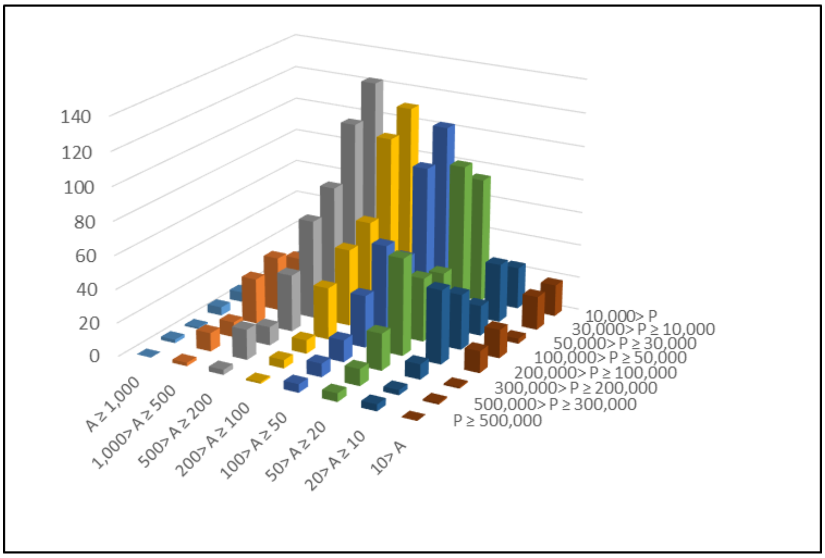

Figure 5.3-3 Counts of local governments in Japan (Day time populations and areas) (Derived from [8] and [9])

Table 5.3-3 Counts of local governments in Japan (Area vs. Day time population density) (Derived from [8] and [9])

Area ＼ Population	50> PD	100> PD ≥ 50	200> PD ≥ 100	500> PD ≥ 200	1,000> PD ≥ 500	2,000> PD ≥ 1,000	5,000> PD ≥ 2,000	PD ≥ 5,000	Total
A ≥ 1,000	15	5	4	3	0	0	0	0	27
1,000> A ≥ 500	73	34	31	29	4	2	0	0	173
500> A ≥ 200	152	83	71	70	29	18	1	0	424
200> A ≥ 100	86	58	56	93	34	23	6	0	356
100> A ≥ 50	42	33	57	73	54	36	29	12	336
50> A ≥ 20	8	17	26	70	50	39	57	64	331
20> A ≥ 10	2	2	3	12	18	18	47	69	171
10> A	2	1	2	3	5	10	18	33	74
Total	380	233	250	353	194	146	158	178	1892

(A: Area in km^2, PD: Daytime Population Density)

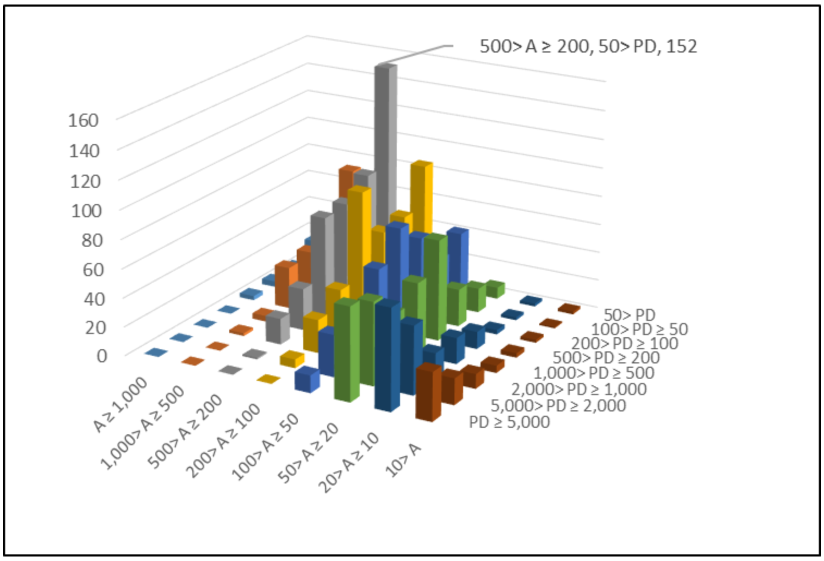

Figure 5.3-4 Counts of local governments in Japan (Area vs. Day time population) (Derived from [8] and [9])

By sorting municipalities in descending order of daytime population density and comparing each municipality's size as well as daytime population to the total area of all municipalities in Japan, Figure 5.3-6 provides a 'portfolio' of these organizations in the context of the daytime population density. The population density curve has a lolled-S shape. The daytime population gradually decreases while the size of the corresponding area increases as the daytime population density decreased. Though there are fluctuations in every sample, the approximated dashed lines show the overall tendency.)

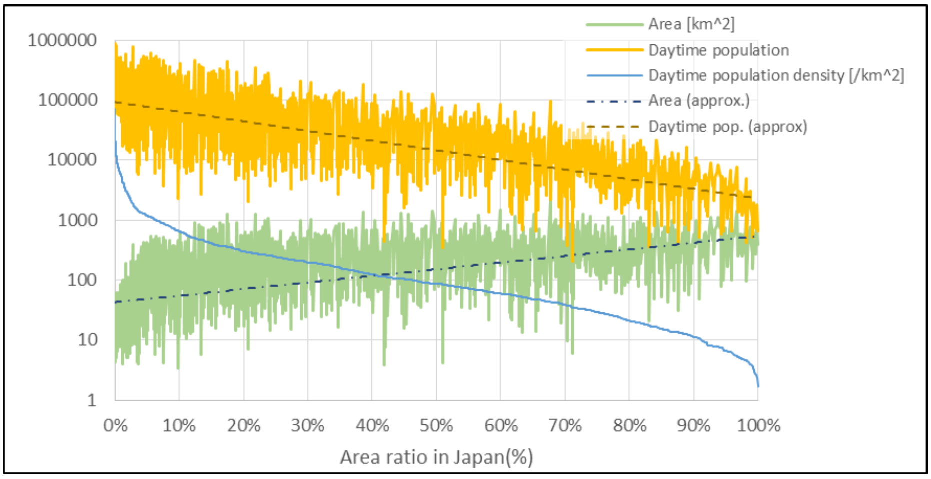

Figure 5.3-5 Profile of local municipalities (Area, Population and Population density) (Derived from [8] and [9])

Figure 5.3-6 depicts the cumulative daytime population curve against the cumulative area of corresponding municipalities with the descending order of the daytime population density. It can be observed that 95% of the total population of the nation spends the daytime in municipalities which encompasses 50.1% (see point (a) in the figure) of land of the nation. In these areas, the daytime population density is higher than 85 people per square kilo meter (point (b)). In the case of only half of the total population, i.e. 50% of the nation's gross population, the area where they spend their daytimes corresponds to only 3.7% of the total area (point (c)) and the population densities of these areas is larger than 1,396 people per square meter (point (d)).

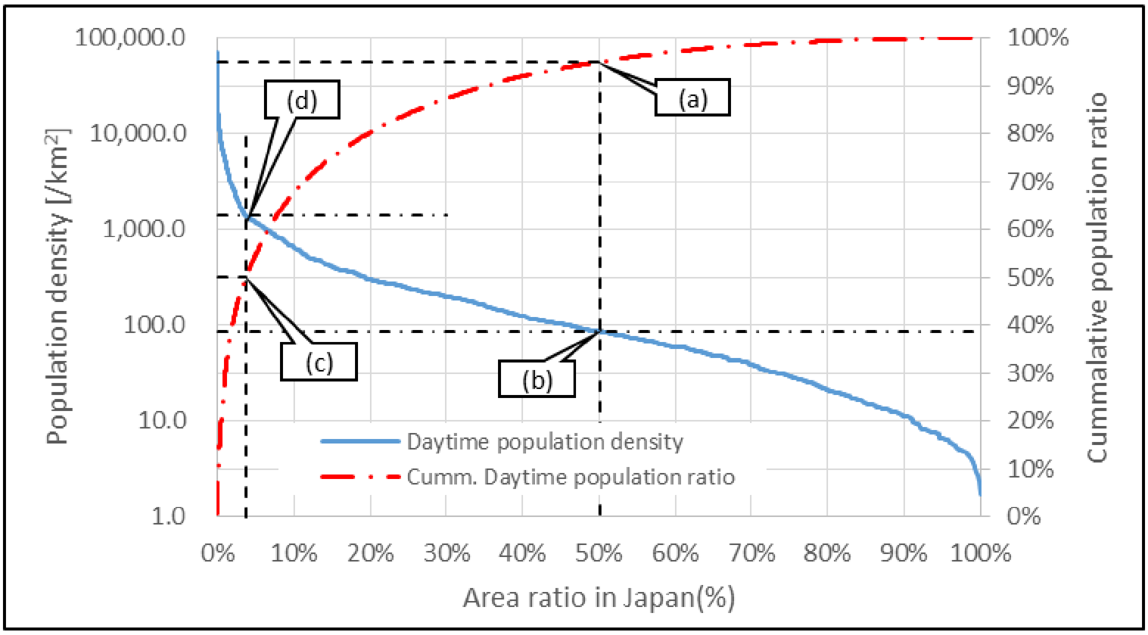

Figure 5.3-6 Cumulative area vs. Population density and Cumulative population (Derived from [8] and [9])

As an experiment, costs were estimated for the case which mobile networks are operated in the areas in which daytime population densities are less than 200/km^2 was derived using equation (2) [6]. The results are expressed in Figure 5.3-7 (Derived from [6], [8] and [9]). Operation cost increase constantly as the coverage of the area increases, reaching 1,000 billion yen when the network covers areas which daytime population density is down to 50/km^2.

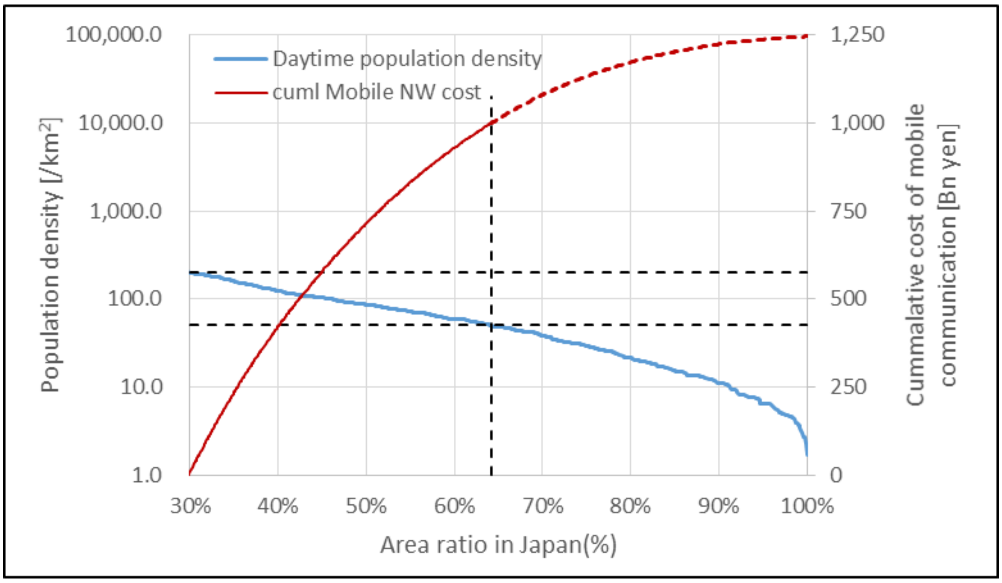

Figure 5.3-7 Cumulative cost of mobile communication networks of areas of population density between 50 to 200 (Derived from [6], [8] and [9])

The last experiment uses equations derived from existing mobile networks, resulting in enormous costs. Therefore, when considering a '5G' system, an efficient technologies/deployment approach could be applied when the system covers a sparsely populated area in the nation.

5.4 Daily dynamics aspect

An example of daily dynamics of population densities during the day and at night in local municipalities within the Tokyo metropolitan area is shown in Figure 5.4-1 (Derived from [8] and [9]). The figure captures the thirty densest areas in the region, showing the enormous changes in population densities between the daytime and nighttime. In terms of population density changes, the most extreme case within a municipality (Chiyoda-ku in Tokyo) has a 17 times higher population density during the daytime period compared at night. Existing mobile communication networks have been able to handle these large population density swings in dense, urban areas.

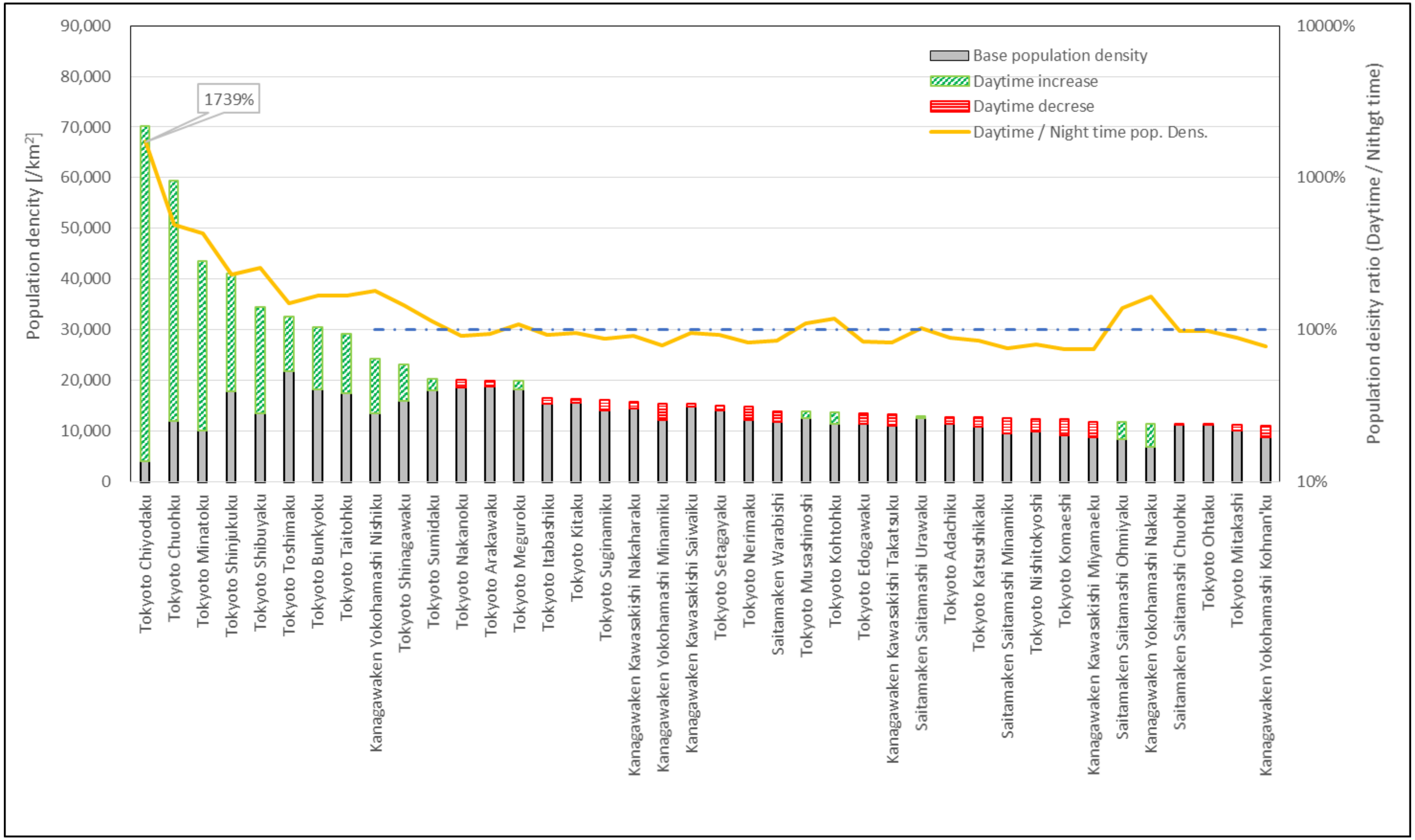

Figure 5.4-1 Dynamics of population density (day time and night time in Tokyo metropolitan area) (Derived from [8] and [9])

Figure 5.4-2 (Derived from [8] and [9]) shows the nature of daily population dynamics nationwide by sorting out daytime populations (not densities) and nighttime populations in each local municipality by their daytime populations in descending order. The chart shows that half of the whole population lives and commutes within 10% of the total landmass of the nation, and the most significant dynamics is observed within 10% of the whole population, who lives and commutes within 1% of the total mass.

As the population portfolio shows the net dynamics and because of the bidirectional nature of commuting, the actual flow of the people could be larger than these increases or decreases of daytime and night time populations express. Data showing the actual numbers of commuters can be found in Table 5.4-1[10] where the transportation flow within the Tokyo metropolitan area is summarized. According to this analysis, more than 7,000,000 people are moving in the area on a daily basis. The same survey was taken in the Kansai area around Osaka and Kyoto area as well as in Chukyo area around Nagoya. According to the analysis in [10], total number of commuting people is 2,450,000 and 728,000 respectively.

As has been already pointed out, these numbers reflect the current situation and express how existing mobile communication systems have already been able to cope with them. However, considering growing volume for communication traffic as demand increases as well as a future where many more personal objects will be equipped with communication capabilities, the '5G' system should be capable to handle double or triple the traffic flow as necessary every morning and evening, which would require certain technical breakthroughs.

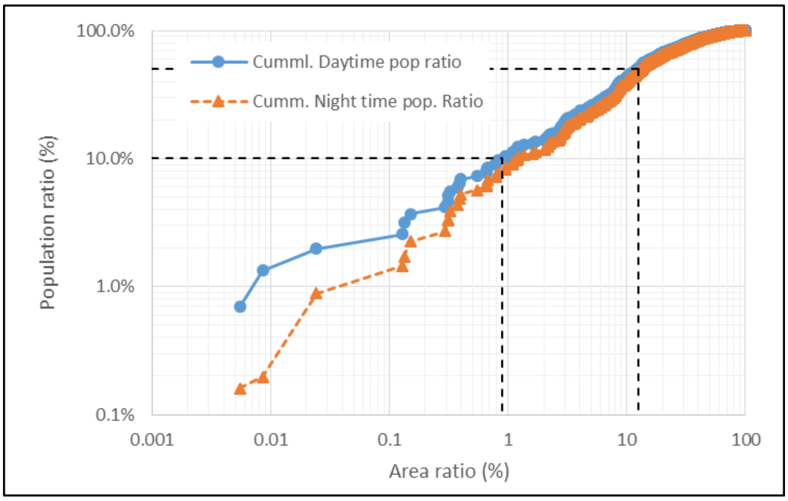

Figure 5.4-2 Dynamics of population (day time and night time in Tokyo metropolitan area) (Derived from [8] and [9])

Table 5.4-1 Transportation flow in Tokyo metropolitan area (English translation from [10])

(Unit: 1000/day, one-say direction)

Start \ Destination		Tokyo			Kanagawa pref.				Saitama pref.			Chiba pref.			Ibakaki pref.	Other prefectures	Area total
		Metropolitan	Other area	Subtotal	Yokohama-shi	Kawasaki-shi	Other area	Subtotal	Saitama-shi	Other area	Subtotal	Chiba-shi	Other area	Subtotal			
Tokyo	Metropolitan	1,767	109	1,876	64	38	21	123	21	45	66	16	43	59	3	0	2,127
	Other area	585	219	804	33	23	22	78	5	16	21	1	5	6	1	1	911
	Subtotal	2,352	328	2,680	96	61	43	200	26	61	87	18	48	65	4	1	3,038
Kanagawa	Yokohama-shi	446	32	478	247	64	80	391	2	4	6	2	4	6	0	0	880
	Kawasaki-shi	239	23	262	41	46	18	105	1	2	3	1	2	3	0	0	372
	Other area	246	46	292	151	40	132	323	0	2	2	1	2	3	0	0	620
	Subtotal	930	101	1,031	439	150	230	819	3	8	11	4	8	12	0	0	1,872
Saitama	Saitama-shi	183	7	190	3	3	1	7	34	34	68	1	5	6	0	0	273
	Other area	622	42	664	10	7	3	20	98	149	247	2	19	21	2	1	953
	Subtotal	805	49	854	14	10	4	28	131	183	314	3	24	27	2	1	1,226
Chiba	Chiba-shi	116	2	118	3	2	0	5	0	2	2	24	28	52	0	0	176
	Other area	607	12	619	10	7	1	18	8	18	26	65	136	201	6	0	871
	Subtotal	723	14	737	12	9	2	23	8	20	28	89	164	253	7	0	1,049
Ibakaki pref.		69	3	72	1	0	0	1	3	2	5	4	10	14	4	0	98
Other prefectures		10	4	14	0	1	0	1	2	2	4	0	0	0	0	0	19
Area total		4,889	499	5,388	562	231	279	1,072	173	277	449	118	253	371	17	2	7,301

5.5 Capital investment aspect

As an additional observation related to costs, capital investment by mobile operators is shown in Figure 5.5-1 (Derived from [12]) in which several investment peaks are observed during every ten-year period. A 30% increase in capital investment can be seen between the years of 2009 to 2014. Since this is an investment for future businesses, it should reflect the long term trends of the market and peaks in the chart should be consistent with a period of deploying new mobile communication systems while the other times would periods where operators are improving their system capacities.

During the time when '5G' will be deployed, a certain amount of capital investment will be needed. However, the way 5G will be deployed should be efficient enough to provide the reasonable service quality and quantity at a reasonable cost as has been discussed in the previous sections.

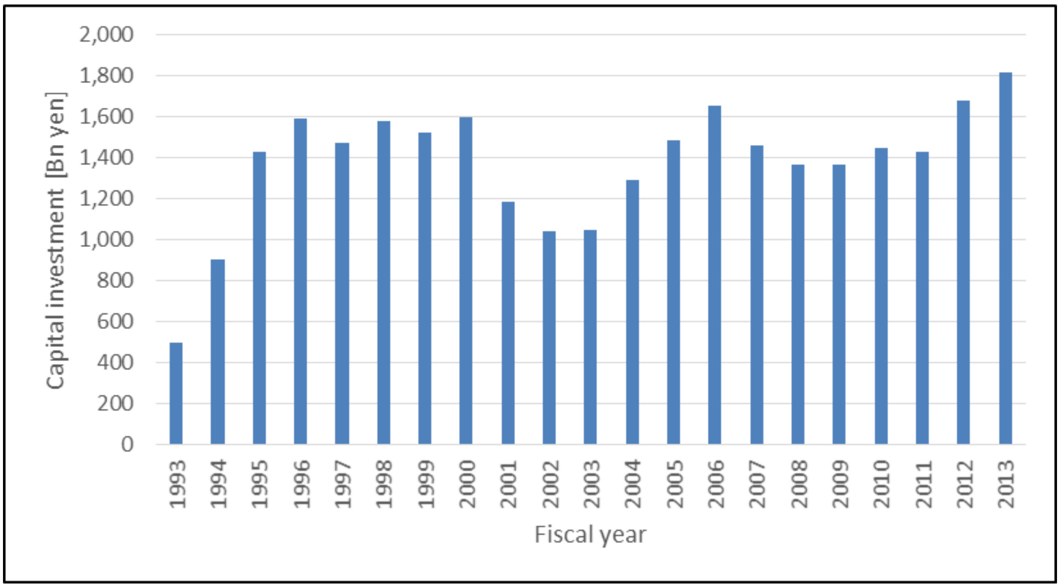

Figure 5.5-1 Capital investment of mobile communication operators in Japan (Derived from [12])

5.6 Conclusion

This chapter reviewed the costs of the mobile communication systems and analyzed it from several '5G' use case perspectives. The case studies considered included looking at costs in relation to communication traffic, as related to mobile broadband and scenarios related to coverage over sparsely populated areas and the dynamics of communication traffic in areas where population density varied throughout the day.

First, the conclusion as related to communication traffic, suggests that '5G' provide wider bandwidth services utilizing, for example, wider frequency spectrum, that would not increase costs dramatically, or even at all, even with the new value provided in terms of new services.

Second, experiments estimating operating costs when deploying mobile communications systems in sparsely dense suggests utilizing an efficient technologies/deployment approach as the '5G' system covers more sparsely populated areas of the nation.

Finally, the dynamics of a widely changing population density as it relates to communication traffic were studied, by calculating the deltas between daytime and nighttime populations in the Tokyo metropolitan area. Traffic as people commute into and out of these areas during the day can double or triple and the '5G' system should be ready to serve these kinds of dynamic population shifts over the course of one day. It should also be noted that all of these above mentioned use cases should also take into account new deployment scenarios that would provide device to device communication as well as the number of wearable devices carried by everyone.

Since an important framework for '5G' is the ability to cover a variety of use cases in a cost effective manner, a '5G' system should be designed to be as flexible and as scalable as possible. Accordingly, in most cases, especially use cases specific to '5G', it would be useful to apply technologies, configurations or operating methods suitable to these specific use cases and combine these elements into a unified communication system, rather than to seek generic, common and robust technologies covering all the use cases in a general manner

References

[1] "Mobile Communications Systems for 2020 and beyond," ARIB 2020 and Beyond Ad Hoc Group White Paper, Oct.2014 (URL: http://www.arib.or.jp/ADWICS/20bah-wp-100.pdf).

[2] "Report on the Ideal Development of Mobile Phone Base Stations," Study Group on the Ideal Development of Mobile Phone Base Stations (MIC), Mar. 2014 (In Japanese) (URL: http://www.soumu.go.jp/main_content/000281538.pdf).

[3] "Status of the mobile communications traffic of Japan (Sep. 2015)," Information and Communications Statistics Database, The Ministry of Internal Affairs and Communications, Nov. 2015 (In Japanese) (URL: http://www.soumu.go.jp/johotsusintokei/field/data/gt010601.xls).

[4] "Results of Households expenditure research," Statistics Bureau, Ministry of Internal Affairs and Communications, 2004-2015 (In Japanese) (URL: http://www.stat.go.jp/data/joukyou/12.htm).

[5] "Basic Survey on the Information and Communications Industry," The Ministry of Economy, Trade and Industry, and Statistics Bureau, Ministry of Internal Affairs and Communications, 2004-2015 (In Japanese) (URL: http://www.soumu.go.jp/johotsusintokei/statistics/statistics07b.html).

[6] "Annual report of on the Japanese Economy and Public Finance 2013," Cabinet Office

Government of Japan, Jul. 2013 (In Japanese) (URL: http://www5.cao.go.jp/j-j/wp/wp-je13/index_pdf.html).

[7] “Annual report of on the Japanese Economy and Public Finance 2013,” Cabinet Office Government of Japan, Jul. 2013 (Summary in English) (http://www5.cao.go.jp/keizai3/2013/0723wp-keizai/summary.html).

[8] “Population based on place of working or schooling (Daytime population), Population based on place of usual residence (Nighttime population), Rate of daytime population to Nighttime population - Shi, Ku, Machi and Mura (2010),” Statistics Bureau of Japan, 2010-2015 (In Japanese) (URL: http://www.stat.go.jp/data/kokusei/2010/kihon4/zuhyou/syuyou.xls).

[9] “Area of Shi, Ku, Machi and Mura in each Ken,” Geospatial Information Authority of Japan, 2015 (In Japanese) (URL: http://www.gsi.go.jp/KOKUJYOHO/MENCHO/201510/opening.htm).

[10] “Report of analysis on the eleventh Metropolis Transportation Census (2010),” Ministry of Land, Infrastructure, Transport and Tourism, Mar. 2013 (In Japanese) (URL: http://www.mlit.go.jp/sogoseisaku/transport/sosei_transport_tk_000047.html).

[11] “Research on investment and retirement of fixed asset of private enterprises (2015),” Cabinet Office Government of Japan, Jul. 2013 (In Japanese) (URL: http://www.esri.cao.go.jp/jp/sna/data/data_list/jyokyaku/files/h26/tables/H26hyou3-1.xls).

[12] “Radio industry year book 2015,” Association of Radio Industries and Businesses, Nov. 2015 (In Japanese) (URL: http://www.arib.or.jp/johoshiryo/nenkan/nenkan.html).