Analysis of TV White Space Availability in Japan

Tsuyoshi Shimomura, Teppei Oyama and Hiroyuki Seki
Fujitsu Laboratories LTD.
3-2-1 Sakado, Takatsu-ku, Kawasaki City, Kanagawa 213-0012, Japan

Abstract—**This paper analyzes TV white space (TVWS) availability in Japan by estimating the amount and distribution of TVWSs across Japan and comparing them with those across the USA. While TVWS regulation is still under discussion in Japan, the expected availability is likely to be more encouraging than that in the USA. Japanese metropolitan areas tend to have more available channels than those in the USA. Including the Tokyo metropolitan area which is the most populated area in Japan, 84.3% of areas (66.7% of the population) may expect greater than 100-MHz TVWSs. The Tokyo metropolitan area is also relatively unaffected by restricted use of the adjacent channel or increase in separation distance.**

Keywords-TV White Spaces; TVWS map; Availability; Propagation model;

I. INTRODUCTION

Ever increasing mobile broadband traffic and bandwidth-intensive applications require additional spectra as well as new technologies to improve network capacity. In this regard, cognitive radio has been intensively investigated for opportunistic access to the spatially or temporally unused spectrum portions [1]. Secondary access to the unused portions in TV bands, so-called TV white spaces (TVWSs), as a promising and practical application of cognitive radio has attracted not only many researchers but also telecom regulators throughout the world. A big advantage of TVWSs is that signals on these bands propagate further than existing Wi-Fi and 3G signals. Many use cases, such as last mile broadband in urban environments, broadband wireless access in rural areas, and wireless sensor networks, have been proposed.

Regarding cognitive access to TVWSs, all TVWS regulations under discussion or that have been released in various countries require TVWS devices to not interfere with existing TV broadcast services. Three approaches, spectrum sensing, geo-location/database, and beacon, have been proposed for this secondary access. In the first approach, a TVWS device detects the vacant channel by sensing before it is used. Since the attenuation of TV signals may vary dramatically due to the landscape and buildings, the detection threshold must be very low. In the second approach, a TVWS device accesses the database to acquire the white space information at its location. Basically, such information is calculated using propagation models. The signals from TVWS devices are expected to attenuate to a sufficiently low level within a required separation distance by reaching the protected area of TV broadcasting. In the last approach, the beacon signals, which contain the white space information, are sent to TVWS devices, which cognize the vacant channels in that locality by decoding the beacon signal.

The US telecom regulator, the Federal Communications Commission (FCC), has led the way in opening up TVWSs. It established rules for unlicensed secondary access to TVWSs in November 2008, and revised them in September 2010 [2][3]. In the updated rules, the geo-location/database method is the primary means for preventing interference to TV stations while the mandatory spectrum sensing requirement was eliminated from the previous version. Recently, the UK regulator, the Office of Communications (Ofcom), has also committed to permitting unlicensed use in TVWSs by leveraging the geo-location/ database method [4].

In Japan, the Ministry of Internal Affairs and Communications (MIC) has also established a working group to discuss effective use of TVWSs. The use of a database is also under discussion. To date, Area limited One-Seg broadcasting, wireless microphones, sensor networks, and public safety communication systems are being discussed to be allowed to operate in TVWSs.

Globally, the switchover from analog to digital broadcast has opened up large portions of VHF/UHF TV bands for new purposes. Many countries, such as the USA, Japan, and those in Europe, have reallocated some of the old TV bands to cellular or/and other services. Finally, how many white spaces are available is an important question for developing commercial applications in TVWSs. While several papers have focused on TVWS availability in the USA, the UK, and some other European countries [1][5][6][7], there is no quantitative information on TVWS availability in Japan. Therefore, we present a quantitative analysis on TVWS availability in Japan. Most of analog TV signals in Japan were terminated on July 24, 2011, except that of the Tohoku region was postponed until March, 2012 in response to the March 11 earthquake. We estimated TVWS availability after the digital TV transition based on a modeling estimation.

The rest of the paper is organized as follows. In Section II we explain the basic concept of the method and criteria of TVWS calculation. This is followed by results of TVWS calculation and TVWS maps in Section III. We analyze TVWS availability in Japan and compare our results with those in the USA in Section III. We conclude this paper in Section IV.

II. METHODOLOGY

Fig. 1 shows the basic concept of TVWS device regulations. TVWS devices must be located outside the protected area by a

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required separation distance based on their transmission power and antenna height. In general, the protected areas of a TV channel are equal to the coverage of the corresponding transmitters/boosters/translators, which can be assumed as a set of points that satisfy the required field strength.

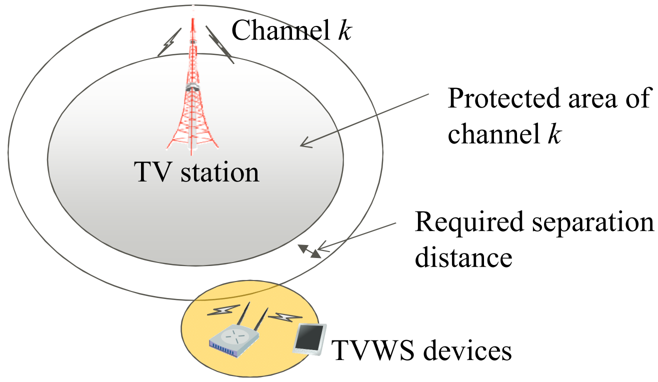


Figure 1 Protected area and required separation distance

A. *Protected areas and propagation models*

We use the ITU-R P.1546 propagation model to estimate the protected areas. Mishra [5] and Van de Beek et al. [6] also used this model for the same purpose. It includes propagation curves for sea paths in addition to land paths. In our simulation, we take account of both types of paths considering that some parts of TV broadcasting coverage in Japan come from propagation over the sea.

The ITU-R P.1546 propagation model provides a set of *F(X, Y)* curves for predicting field strength according to the distance from TV transmitters. The *F(X, Y)* curve is a two dimensional complimentary cumulative distribution function (CCDF) with parameters *X* and *Y*, where *X* specifies a spatial percentage and *Y* specifies a temporal percentage. The *F(50,50)* curve is the median field strength. Fig. 2 shows the *F(50,50)* curves for land and sea paths when the antenna heights of the transmitters are 20 m and 300 m. It can be seen that sea paths yield less propagation attenuation than land paths.

In cases where the radio path is over both land and sea, the mixed path field strength can be calculated using Eq. (1).

$$\mathrm{E} = (1 - \mathrm{A}) \cdot \mathrm{E}_{\mathrm{land}}(\mathrm{d}_{\mathrm{total}}) + \mathrm{A} \cdot \mathrm{E}_{\mathrm{sea}}(\mathrm{d}_{\mathrm{total}}), \qquad (1)$$

where *A* is the interpolation factor, which depends on the fraction of sea paths, and $E_i(d_{total})$ is the field strength for a path in zone *i* equal in length to the mixed path.

In the FCC regulations [3], the protected areas are calculated using R-6602 curves, which do not include sea paths. Fig. 3 shows that the R-6602 curves are almost identical to the propagation curves for the land path in the ITU-R P.1546 model.

B. *Criteria for calculating required separation distance*

Two approaches have been proposed for calculating the required separation distance. The first one is directly based on the minimum desired-to-undesired (D/U) signal power ratio needed for acceptable service. In general, this D/U signal ratio varies according to the nature of the undesired signal, i.e., the signal from TVWS devices. The FCC adopted this approach with the protection ratio of 23 dB for digital TV by assuming the signals from TVWS devices are “noise-like” [2]. As a result, the FCC set the required separation distances listed in Table 1 by setting the maximum equivalent isotropic radiated power of a TVWS device to 4 W. Restricting the use of the channels adjacent to a TV broadcasting channel is not necessary with a TVWS device, provided its power level is reduced to 40 mW or less.

The other approach is based on the interference-to-noise power ratio (I/N ratio). In May 2011, ITU-R published recommendation BT.1895 regarding protection criteria for terrestrial broadcasting systems [9]. This recommendation states that “the total interference at the receiver from all radiations and emissions without a corresponding frequency allocation in the Radio Regulations should not exceed 1% of the total receiving system noise power.” If we assume that a TVWS device has no corresponding frequency allocation, BT. 1895 requires such a TVWS device to be far enough away to ensure that the power of its signals attenuates to 20 dB below the noise power by reaching the protected areas.

Fig. 4 compares the FCC’s rules with ITU-R BT.1895. The FCC’s criterion, labeled “D/U=23dB” in Fig. 4, is converted to I/N ratio on the boundary of the protected area by assuming that the receiver noise figure is 3.3 dB. The antenna gain of TV receivers for interference signals is assumed to be 0 dBi. When the interference signals are received with larger antenna gain, the I/N ratio of the FCC’s criterion increases. Fig. 4 shows that recommendation BT.1895 is at least 5 dB more conservative than the FCC’s criterion.

Table 1 FCC rules on required separation distances[1]

Antenna Height of Unlicensed Device	Required Separation [km] From Digital or Analog TV Protected Contour	
	Co-channel	Adjacent Channel
Less than 3 meters	6.0	0.1
3 - Less than 10 meters	8.0	0.1
10 - 30 meters	14.4	0.74

1. On April 2012, this table was revised. See FCC 12-36 for the latest rules.

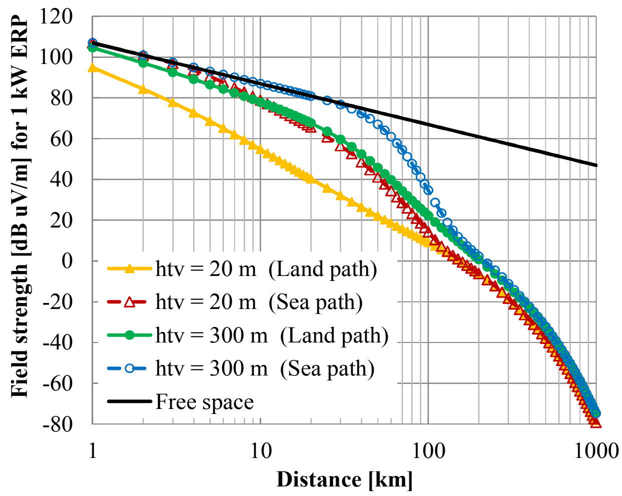


Figure 2 ITU-R P.1546 Propagation Curves

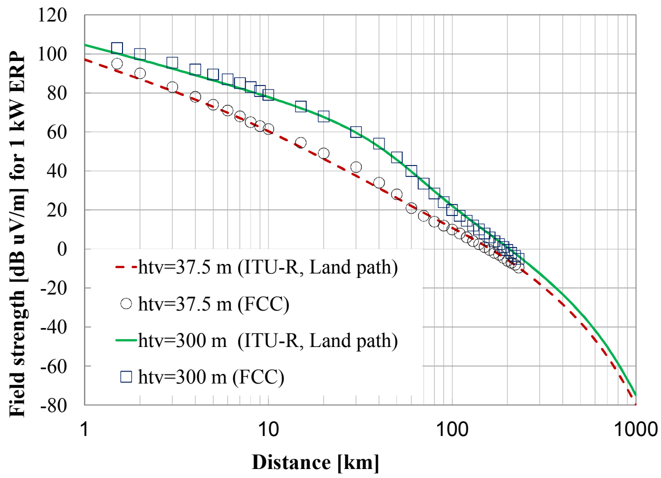


Figure 3 R-6602 curves compared to ITU-R P.1546 propagation curves

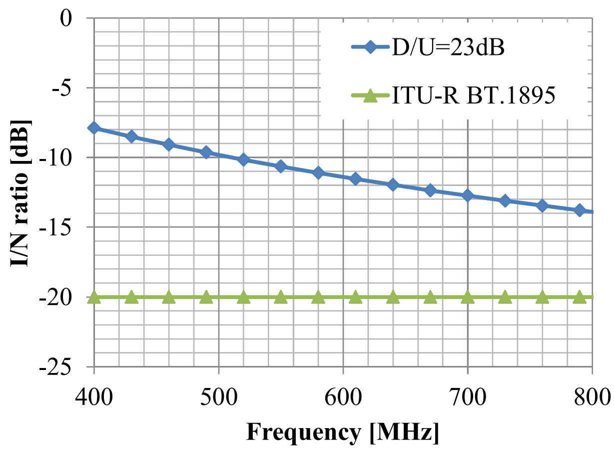


Figure 4 FCC regulation vs. ITU-R BT.1895

III. TVWS AVAILABILITY IN JAPAN

A. Details of TVWS calculation

We first estimate the coverage of a total of 11556 channels, which are transmitted from more than 2000 transmitter/translator/booster sites throughout Japan, based on the information on MIC's website. Basically, a site of transmitters, translators, or boosters is shared by multiple TV stations. We then calculate the white space by defining a minimum separation distance.

By March 2013, all the channels of digital terrestrial TV broadcasting in Japan will eventually be repacked in the frequency band from 470 to 710 MHz. The total bandwidth of 240 MHz is divided into 40 physical channels numbered 13-52. Table 2 lists major TV channel allocation in the three largest metropolitan areas in Japan.

Because the rules for TVWS devices in Japan are currently under discussion, some basic criteria from FCC regulations are adopted into our estimation. We estimate TVWS availability based on the FCC's approach by using the ITU-R P.1546 propagation model. We use F(50,90) for the propagation curve. The criterion for the protected area is a field strength of 41 dBuV/m.

Table 2 Physical TV Channel allocation in three largest metropolitan areas

Channel	13	14	15	16	17	18	19	20	21	22
Tokyo				tv					tv	tv
Osaka	tv	tv	tv	tv	tv	tv				
Nagoya	tv					tv	tv	tv	tv	tv

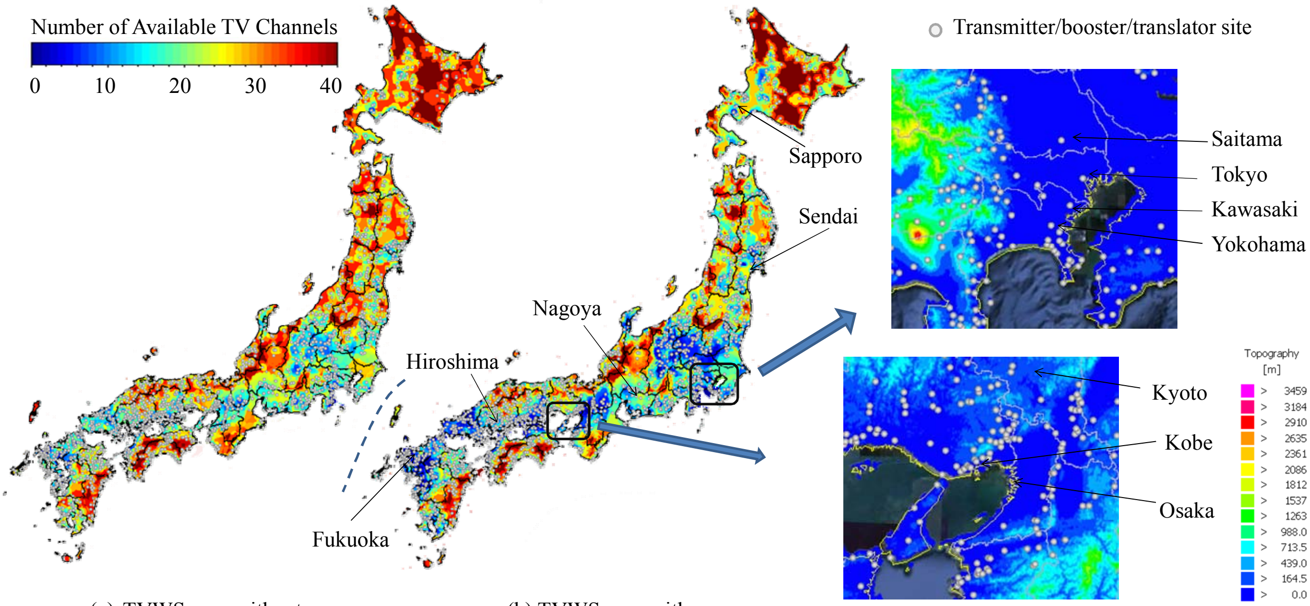
23	24	25	26	27	28	29	30	31	32	33-52
tv	tv	tv	tv	tv	tv					
	tv									
tv										

For geographical information, we use version 2 of the Shuttle Radar Topography Mission (SRTM) digital topographic data [10]. To predict the field strength more accurately, terrain clearance angle correction is also conducted based on ITU-R P.1546. The latitude and longitude resolution is 0.01°. The area and population information per municipality on MIC's website [11] is also used to analyze the distribution of TVWS.

B. TVWS availability

Fig. 5 shows the TVWS maps calculated based on the separation distances for antenna height of less than 3 m in Table 1. From the comparison of the results without/with restricting the use of adjacent channels in Figs. 5(a) and (b), respectively, it can be seen that the number of available channels decreases largely by restricting the use of adjacent channels. To make the topology of site location more visible, the maps around Tokyo and Osaka with topography background are enlarged in Fig. 5(c). Basically, the plains are covered by large power transmitters, and mountains and hills are covered by translators and boosters. Since the Tokyo metropolitan area is located in the largest plain in Japan, the transmitters there have the highest power. Fig. 5 shows that the amount of TVWSs tends to decrease as the number of nearby transmitters/translators/boosters increase. According to the MIC, the household coverage of terrestrial digital TV signals in Japan exceeded 98% at the end of 2010. Many translators and boosters have been installed to cover relatively thin populated area. In the central Tokyo area there are around 20 or 27 channels available with or without considering adjacent channel interference to digital TV channels. On the other hand, many rural/small-town areas have less availability than central Tokyo. Furthermore, some mountainous regions have much less availability.

Fig. 6 shows the CCDF of available channels according to different separation distances. The CCDF is calculated in two ways, by area or population. The separation distance of 0 km may be seen as the upper boundary of TVWS availability. The number of available channels decreases largely by increasing the separation distance. The median value by area, for instance, decreases from 26.1 to 17.3 by increasing the separation distance from 6 km to 14 km, whereas that for 0 km is 34.0. The separation distance depends on the antenna height and power level as per the FCC rules. It also depends on the criterion for protecting TV broadcasting, as discussed in Section II. Careful decision on the calculation methodology is



(a) TVWS map without restricting use of adjacent channel

(b) TVWS map with restricting use of adjacent channel

(c) Site locations and terrain

Figure 5 TVWS maps of Japan

necessary since TVWS availability is affected largely by separation distance.

As an easy-to-follow measure for TVWS availability, we focus on the 100-MHz availability, which means an average of 16.7 available channels. Fig. 6 shows that 84.3% of areas (66.7% of population) in Japan may have greater than 100-MHz TVWSs for 6-km minimum separation distance. When the minimum required separation distance is 14 km, 53.9% of areas (33.6% of population) in Japan may have greater than 100-MHz TVWSs. All the CCDF curves by population have a vertical drop point around the 27-28 channels. Most of the population who may expect 27-28 available channels in his/her location is in the Tokyo metropolitan area. This reflects the fact that the Japanese population is concentrated in the capital area. It is interesting that the vertical drop point moves only a little despite the fact that the separation distance changes dramatically. This is because a large portion of the Tokyo metropolitan area is covered by a few extra-large power transmitters and far from other boosters/translators.

Fig. 7 shows the average number of available channels of twelve heavily populated cities with populations of more than 1 million. When the separation distance is 6 km, the average number of available channels ranges from 14-30. Five cities, Tokyo, Sapporo, Kawasaki, Saitama, and Sendai, may expect more than 20 available channels (120 MHz) for secondary use. When the separation distance is 14 km, the average available channel ranges from 6-21. As stated above, the available channels of the cities in the Tokyo metropolitan area, Tokyo, Kawasaki, and Saitama, are less affected in response to separation distance changes. The number of available channels in Hiroshima varies dramatically in response to separation distance changes. In fact, Hiroshima receives broadcasting signals not only from the nearby transmitters/translators/boosters but also from those on the other side of the Seto Inland Sea since signals propagate farther over the sea-paths than the land-paths, as shown in Fig. 2.

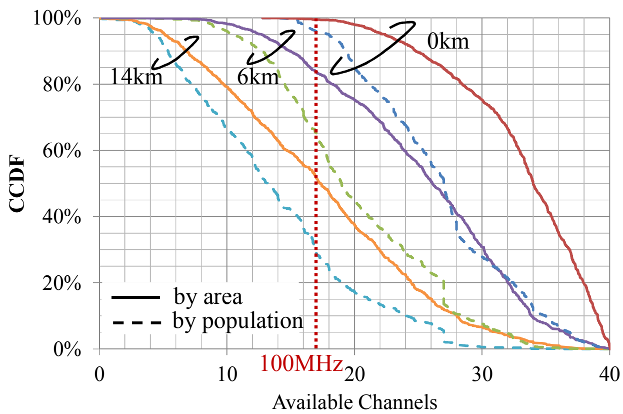


Figure 6 CCDF of available channels

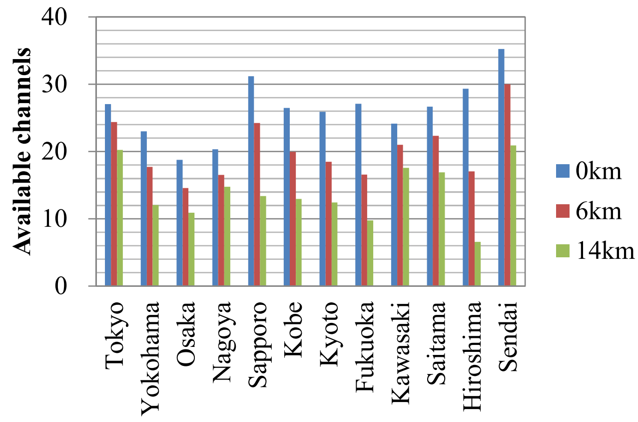


Figure 7 Expected available channels of Japanese metropolitan areas

C. Comparison between Japan and USA

The above results imply that TVWS availability in Japan is different from that in the USA. Reports from the USA suggest a paradox in which larger cities have less TVWSs [5][12]. The metropolitan areas in the USA have less than 8 white space channels for a TVWS device with a 30-m antenna height where the total number of channels is 47. This paradox does not seem to be applicable to Japan. First, Tokyo has much more TVWSs than North American metropolitan areas mainly due to less TV stations. Second, some thinly populated mountainous regions have only a few TVWSs as a result of many boosters/translators having been installed to expand terrestrial broadcasting coverage throughout Japan.

Mishra [5] also provides results of expected TVWS channels averaged by area or population in the USA with antenna heights of 30 m under the same conditions with the above calculation. Since the allocation for digital TV in Japan is proximate to the low UHF band allocation in the USA, we compared the expected channels between them as shown in Table 3. The notations *A1* and *A2* denote the expected values averaged by area, and *P1* and *P2* denote the expected values averaged by population. Table 3 suggests two significant differences.

- Without adjacent channel consideration, Japan has less expected channels than the USA even though only the low UHF band is counted for the USA. However, the number of average channels by population compared to that by area decreases to a lesser degree in Japan than in the USA.
- Restricting the use of adjacent channels decreases the available channels in Japan to a lesser degree than in the USA.

The first difference may be explained by the fact that Japan has a higher population density and higher household coverage. The second difference may be explained by the rather continuous channel allocation for metropolitan areas, as shown in Table 2. The available channels for TVWS devices that neighbor the channels used by TV are limited. Both Fig. 5 and Table 3 suggest that the metropolitan areas, as well as rural areas, in Japan seem to be a good market for TVWS devices. Since heavily populated areas generally demand additional spectra, TVWS availability in Japan is likely to be more encouraging than that in the USA.

IV. SUMMARY

We presented an analysis of TVWS availability in Japan, where 84.3% of areas (66.7% of population) may expect greater than 100-MHz TVWSs for 6-km minimum separation distance. The most populated area, i.e., the Tokyo metropolitan area, has much more available channels than the metropolitan areas in the USA. The number of available channels in the Tokyo metropolitan area also decreases to a relatively lesser degree due to the increase in the separation distance or restricting the use of adjacent channels. TVWSs seem to be promising for accommodating many new communications devices in Japan according to amount and distribution of TVWS.

Table 3 Comparison of expected available channels

		Japan	USA (LUHF)
Number of channels in target band		40	37
Frequency range [MHz]		470 -710	470 - 608, 614 - 698
Expected available channels without adjacent channels consideration	*A1*	17.4	23.8
	P1	13.8	16.1
Expected available channels with adjacent channel consideration	*A2*	14.1	14.9
	P2	9.2	5.82
Rate of decrease	*A1 -> P1*	21%	32%
	A2 -> P2	35%	61%
Rate of decrease	*A1 -> A2*	19%	37%
	P1 -> P2	33%	64%

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