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Final report for OFCA

Re-assigning the spectrum in the 1.9–2.2GHz band

Impacts on service quality and customers of adopting a hybrid between administratively-assigned and market based approach

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NETWORK STRATEGIES
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0 Executive summary

This study contains an independent and objective quantitative assessment on the impact on mobile service quality and customers if the Hong Kong Government decides to adopt a hybrid approach in re-assigning the frequency spectrum in the 1.9–2.2GHz band (“3G spectrum”). The hybrid approach encompasses offering the right of first refusal to the incumbent 3G Mobile Network Operators (MNOs) for two-thirds of their existing spectrum holdings in this band (i.e. 2×10MHz) and the re-auction of the remaining one-third (i.e. 2×5MHz).

0.1 Selection of likely spectrum re-assignment scenarios

We have assumed that each of the four incumbent MNOs will exercise the right of first refusal and retain two-thirds of its spectrum. This leaves one-third of each MNO’s spectrum to be re-auctioned.

We consider that on balance it is unlikely that there will be substantial interest from completely new market entrants in this spectrum. However an existing MNO without 3G spectrum would be interested in obtaining spectrum in this band so we need to consider possible scenarios in which incumbent MNOs lose some of their re-auctioned spectrum to this MNO, as well as scenarios in which incumbent MNOs lose spectrum to other MNOs.

After careful consideration of all possible spectrum re-assignment scenarios we conclude that the following are most likely:

- one incumbent MNO loses its re-auctioned spectrum to another incumbent MNO (Scenario 2a)

- two incumbent MNOs lose re-auctioned spectrum to two other incumbent MNOs (Scenario 2b)
- one incumbent MNO loses its re-auctioned spectrum to the MNO without 3G spectrum (Scenario 2c)
- two incumbent MNOs lose re-auctioned spectrum to the MNO without 3G spectrum (Scenario 2d).

We believe that the least likely scenario is that the MNO without 3G spectrum will acquire all of the re-auctioned spectrum. Nevertheless this does represent the extreme case, and therefore we have included this scenario in our study as a reference point and for completeness (Scenario 3).

The impact on service quality of the four most likely scenarios and the extreme scenario has been assessed against a base case or *status quo* scenario in which all four incumbent MNOs retain all of their existing 3G spectrum holdings.

0.2 Impact assessment methodology

We developed a bottom-up impact model to assess the effect on quality of service of the selected scenarios – in hotspots[1] and territory-wide – across the 3G network and the entire Hong Kong mobile network (deploying spectrum in 2G, 3G and 4G bands). It should be noted that this is a very different approach to that used by OFCA in the second consultation paper and as such there is no relationship between OFCA's previous estimates and those obtained from our model.

The model consists of two parts – demand and supply – and covers a six-year modelling period, 2013–2018. This timeframe encompasses the period leading up to the spectrum reassignment as well as the transitional period after the reassignment. We believe that a two-year post-reassignment period is ample for an incumbent MNO to re-configure its network in order to re-establish quality of service levels after losing re-auctioned spectrum.

1 Hotspot sites are defined as the busiest sites (generally 15% or 20% of the total sites) which carry 40% of the entire network traffic.

The model assesses the impact on service quality by calculating and comparing changes in design capacity overage (DCO). For the purposes of this study, design capacity is defined as 75% of the total network capacity. DCO is assumed to mean the percentage of demand that is unable to be met by design capacity. The model also calculates for reference the changes in throughput, which is defined as the lesser of demand and total network capacity.

It should be noted that our model differs from network planning models used by MNOs for dimensioning and operating their networks, or models designed to assess quality on a per-site or per-customer basis. We consider that our model, including the above metrics, would provide a reasonable high level assessment for quality of service to achieve the objectives of the study. We evaluated five possible mitigation strategies for reducing potential degradation in customer service:

- acquiring additional spectrum
- spectrum refarming
- improving spectrum efficiency
- increasing the number of cell sites
- offloading to WiFi networks.

Our conclusion was that in the Hong Kong environment further spectrum refarming will be the only effective strategy during the model time horizon. As such the mitigation strategies applied in the model scenarios are:

- refarming some 2G spectrum to 3G and 4G
- postponing refarming of some spectrum currently deployed for 3G services to 4G.

Note that the base case scenario includes the current refarming plans of the operators.

In order to reflect the Hong Kong environment we have attempted, as much as possible, to use data supplied by the MNOs for this study. Indeed, we would like to acknowledge that the MNOs have been very generous in their time and information for the model development and this analysis would not have been possible without their input. Any additional assumptions are based on publicly available information and our own internal databases. These assumptions were presented to MNOs, together with an opportunity for feedback. Following this consultation we further refined the model to address operator comments.

0.3 Results

Base case scenario

This is the *status quo* scenario in which all four incumbent 3G MNOs retain all of their existing 3G spectrum holdings.

For the entire Hong Kong territory-wide mobile network as well as the 3G territory-wide network, the DCO results show that there is sufficient network design capacity to accommodate all demand. This is due to the fact that there is significantly more capacity than demand on the 4G networks at present.

For the entire hotspot network, the DCO results show that there is sufficient network design capacity to accommodate all demand throughout the modelling period, except in 2018 when the DCO is 5% in the base case scenario. As already noted, we have defined the design capacity as 75% of the total network capacity. Thus, provided that the DCO figure is below 25%, demand can still be met by the total network capacity.

For the 3G hotspot network, the DCO figures are positive, indicating that network design capacity is insufficient to accommodate all demand even in the base case scenario, giving rise to an impact on service quality. The 3G hotspot DCO increases from 16% in 2013 to 37% in 2014, due to an increase in demand and the refarming of **[✂…..]CI** of spectrum currently deployed for 3G services to 4G by **[✂……...]CI**, resulting in less 3G spectrum and hence increasing the DCO in the 3G hotspot network. The DCO figure starts to decrease gradually from 37% in 2014 to 33% in 2017 in the base case as traffic is migrated from the 3G to the 4G networks. In 2018 there is an increase in DCO to 40% because **[✂…...]CI** of spectrum currently deployed for 3G services is refarmed to 4G by **[✂ ….......]CI**.

The likely scenarios

For the entire Hong Kong territory-wide mobile network as well as the 3G territory-wide network, the DCO results show that there is sufficient network design capacity to accommodate all demand under the four likely scenarios. The DCO figures show that the spectrum re-assignment does not have any impact on the service quality for the entire Hong Kong territory-wide mobile network, as well as the 3G territory-wide network.

For the entire hotspot network, the DCO results show that under the four likely scenarios there is sufficient network design capacity to accommodate all demand through the modelling period to 2017, which means the spectrum re-assignment has no impact on the service quality for the entire hotspot network through the modelling period to 2017. In 2018, the DCO either stays at the same level or decreases from the base case figure of 5% on the entire hotspot network under the four likely scenarios. This means that the spectrum re-assignment does not worsen the DCO level in 2018 experienced in the base case scenario, and in fact would in some instances alleviate the magnitude of DCO. The DCO results show that none of the likely re-assignment scenarios would have the effect of worsening service quality from the base case situation that already exists in the entire hotspot network in 2018.

For the 3G hotspot, the DCO figures are positive during the modelling period. The percentage point changes from the base case indicate that DCO either stays at the same level or decreases from the base case on the 3G hotspot network under the four likely scenarios. The DCO results show that none of the likely re-assignment scenarios would have the effect of worsening service quality from the situation that already exists in the 3G hotspot network in the base case scenario.

Extreme scenario

Under the most unlikely (extreme) scenario in which the MNO without 3G spectrum obtains all re-auctioned spectrum (scenario 3), the DCO figures indicate that there is sufficient network design capacity to accommodate all demand for the entire Hong Kong territory-wide mobile network as well as the 3G territory-wide network. The DCO figures show that under this scenario, the spectrum re-assignment does not have any impact on service quality for the entire Hong Kong territory-wide mobile network as well as the 3G territory-wide network when compared to the base case scenario.

For the entire hotspot network, the DCO results show that under the extreme scenario there is sufficient network design capacity to accommodate all demand through the modelling period to 2017, which means the spectrum re-assignment has no impact on the service quality for the entire hotspot network through the modelling period to 2017. In 2018, the entire hotspot DCO slightly decreases from the base case. The DCO results show that the extreme scenario would not have the effect of worsening service quality from the base case situation that already exists in the entire hotspot network in 2018.

For the 3G hotspot network, the DCO figures are positive during the modelling period. Under the extreme scenario, the 3G hotspot DCO is reduced by 3 percentage points from the base case. This result is due to the effect of increased total network capacity in the model, mainly because of the assumption that the MNO without 3G spectrum will build more base stations if it obtains all re-auctioned spectrum. The DCO figures show that in the extreme scenario service quality will not be worsened, compared to the situation that already exists at 3G hotspot network in the base case scenario.

Impact on 3G hotspot network on per operator basis

Under all scenarios, the ranges of percentage point change in DCO in the 3G hotspots from the base case show that for the most affected incumbent 3G MNO, the maximum increase in DCO in 2016 from the base case is approximately 12 percentage points. With mitigation measures, the increase in DCO in 2016 for the most affected MNO would be reduced to a range of one to four percentage points, indicating that mitigation measures are effective in reducing the DCO level.

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NETWORK STRATEGIES

1 Introduction

This study contains an objective quantitative assessment of the impact on service quality and customers if the Hong Kong Government decides to adopt a hybrid approach (combining an administratively assigned and market based approach) in re-assigning the frequency spectrum in the 1.9–2.2GHz band.

In October 2001, a total of 2×59.2MHz paired spectrum lots in the 1.9–2.2GHz spectrum band were assigned to four mobile network operators (MNOs)[2] through auction. This was a 15-year spectrum assignment, due to expire in October 2016. All of the allocated spectrum in the 1.9–2.2GHz band is used to provide 3G services by the incumbent MNOs. A fifth MNO, China Mobile, is the only one without 3G spectrum.

According to the Spectrum Policy Framework of 2007, spectrum assignees should not have any expectation of right of renewal or right of first refusal of any spectrum upon the expiry of a spectrum assignment.[3] Thus, the Secretary for Commerce and Economic Development (SCED) and the former Telecommunications Authority (TA) released the first consultation paper seeking comments on the following three possible options for re-assignment of the spectrum:[4]

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2 The four MNOs assigned spectrum in the 1.9–2.2GHz band were CSL Limited, Hong Kong Telecommunications (HKT) Limited, Hutchison Telephone Company Limited and SmarTone Mobile Communications Limited.

3 Commerce and Economic Development Bureau (2007), *Radio Spectrum Policy Framework,* available at http://www.cedb.gov.hk/ctb/eng/legco/pdf/spectrum.pdf.

4 Commerce and Economic Development Bureau and the Communications Authority (2012), *First Consultation Paper on Arrangements for the Frequency Spectrum in the 1.9 – 2.2GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services,* available at http://www.coms-auth.hk/filemanager/common/policies_regulations/consultations/papers/cp20120330.pdf.

- **Option 1: Administratively assigned approach** – right of first refusal to be offered to the incumbent MNOs
- **Option 2: Market-based approach** – re-auction all the spectrum
- **Option 3: Hybrid approach** – right of first refusal to the incumbent MNOs for two-thirds of the existing spectrum and re-auction for the remaining one-third spectrum.

Having taken into consideration the submissions and responses received for the first consultation[5], SCED and the Communications Authority (CA) have released a second consultation paper seeking further comments on Option 3 (depicted in Exhibit 1.1).[6]

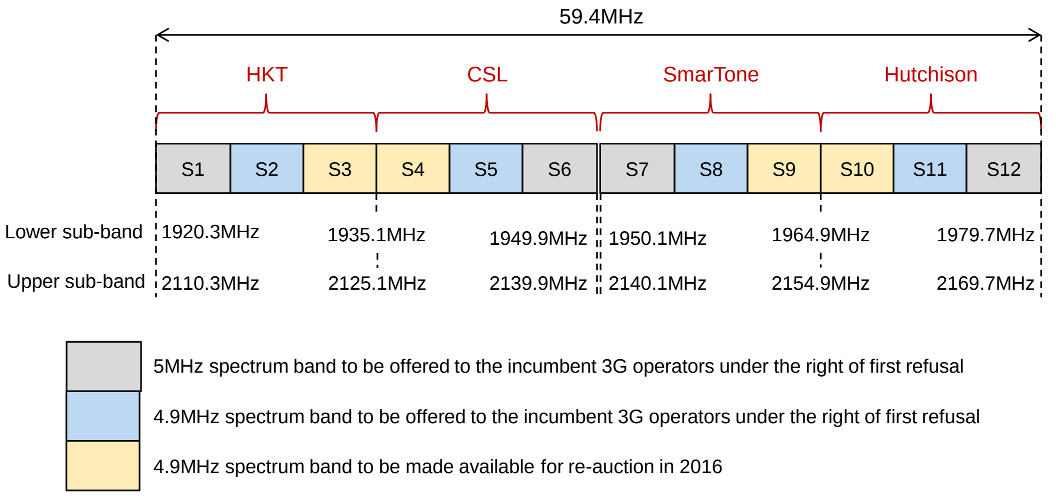


Exhibit 1.1: *Option 3: Hybrid approach for re-assignment of the spectrum in the 1.9–2.2GHz band [Source: OFCA]*

Although this study was commissioned by the Office of the Communications Authority (OFCA) on behalf of the Hong Kong Government, the views expressed in this report are entirely those of Network Strategies.

5 Communications Authority website, *Completed Consultations & Submissions,* available at http://www.coms-auth.hk/en/policies_regulations/consultations/completed/index_id_132.html.

6 Commerce and Economic Development Bureau and the Communications Authority (2012), *Second Consultation Paper on Arrangements for the Frequency Spectrum in the 1.9 – 2.2GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services,* available at http://www.coms-auth.hk/filemanager/en/share/cp20121228.pdf.

Following the current Introduction this report is structured as follows:

- a situation analysis encompassing supply and demand side issues in Hong Kong (Section 2)
- an analysis of likely auction outcomes if Option 3 is adopted in this spectrum re-assignment exercise (Section 3)
- an overview of our forecasting framework for the Hong Kong market (Section 4)
- a discussion of potential mitigation strategies that could be employed to address the effect of a potential partial loss of spectrum (Section 5)
- an outline of the impact model that we have developed to assess the impact on service quality of possible outcomes from Option 3 (Section 6)
- a summary of the results from the impact model (Section 7).

In the Annexes we provide information on current spectrum holdings in Hong Kong, and a summary of responses to operator feedback on the preliminary model and results.

Any confidential information within the report has been removed and enclosed in square brackets as follows: **[✂…]CI**.

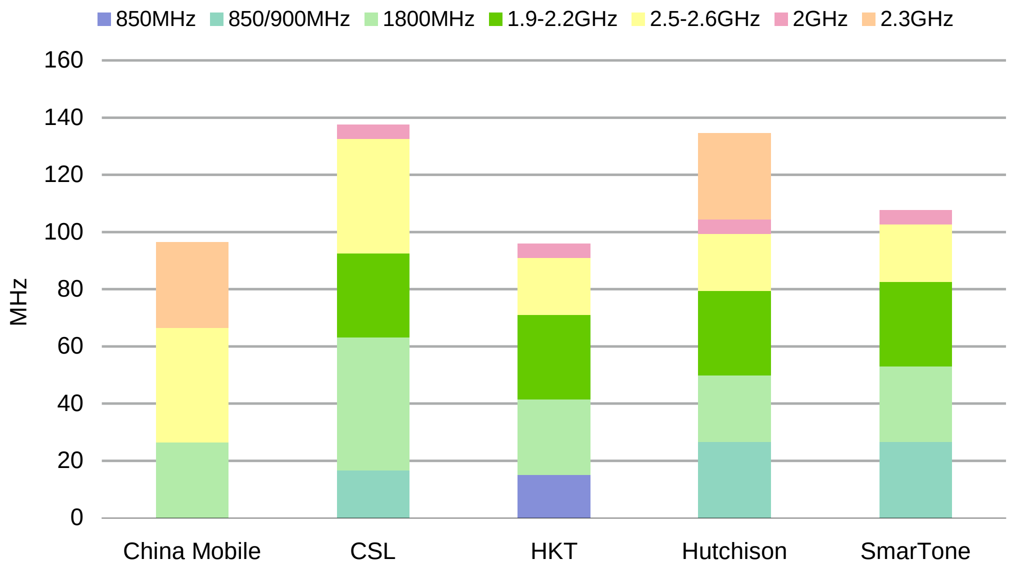
2 Situation analysis

2.1 Spectrum supply

Radio spectrum is a limited resource and an essential resource for all MNOs. Currently, MNOs in Hong Kong are using spectrum in the 800–900MHz, 1700–1900MHz, 1.9–2.2GHz and 2.5–2.6GHz bands to serve their customers (Exhibit 2.1). Spectrum in the 2.3GHz band was released to the market in February 2012 through auction, but the successful bidders have not yet deployed this band commercially.

A total of 572MHz[7] of spectrum for the provision of mobile services has been awarded through auctions, the most recent being the auction held in March 2013 for the assignment of 2×25MHz in the 2.5–2.6GHz band, and other allocation mechanisms.

7 This figure does not include 8MHz spectrum in the 700MHz band released through auction in June 2010 for the provision of broadcast-type mobile services, and 30MHz of unpaired spectrum in the 2.3GHz band awarded to 21 ViaNet which is to be used for the provision of fixed services.



1. All the bands are paired with the exception of 2GHz and 2.3GHz.

2. 40MHz in the 2.5–2.6GHz spectrum band is shared equally by Hutchison and HKT through a joint venture under Genius Brand Limited.

3. The unpaired block in the 2GHz band was assigned together with the paired block in 1.9–2.2GHz but not deployed by any operator due to lack of commercially appealing technology for the band.

Exhibit 2.1: *Hong Kong MNO spectrum allocation [Source: OFCA]*

In general, and without considering the characteristics of each different frequency band, there is no clear position of dominance by any of the MNOs in regards to total assigned spectrum. CSL and Hutchison both hold about 24% and 23.5% of the total allocated spectrum respectively, SmarTone around 19%, and China Mobile and HKT about 17% each.

Technology deployments

Currently 2G mobile services (GSM) are mainly provided using a total of 2×44.3MHz of paired spectrum in the 850–900MHz and 1800MHz bands. In the light of the increasing demand for 3G and 4G services, operators have refarmed some of the spectrum originally intended to provide 2G services. By 2013 3G technology has been deployed over a total of

2×20MHz of paired spectrum in the 850–900MHz band, of which 2×10MHz was originally intended for 3G at launch while the other 2×10MHz has been refarmed from 2G to 3G. In addition 2×45MHz in the 1800MHz band has been refarmed from 2G to 4G services (Exhibit 2.2).

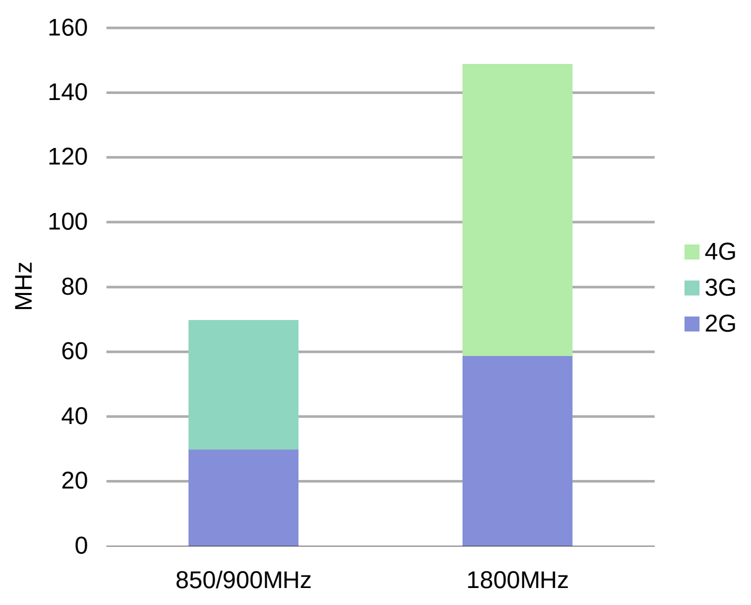


Exhibit 2.2: *Technology deployment status in 850–900MHz and 1800MHz bands, 2013 [Source: OFCA and operators]*

With the inclusion of the refarmed spectrum, a total of 2×86.7MHz in the 850MHz, 850–900MHz, and 1.9–2.2GHz bands is primarily used to provide 3G mobile services, with the majority of that spectrum (2×59.2MHz) in the 1.9–2.2GHz band. Of the latter, 2×19.6MHz[8] would potentially be re-assigned through an auction process if Option 3 is selected.

The use of the frequencies 825–832.5MHz paired with 870–877.5MHz is restricted to the use of CDMA2000 technology for provision of 3G services:

8 2×19.6MHz corresponds to the exact quantity of spectrum to be re-auctioned, comprising four slots of 2×4.9MHz each from the original holding of the incumbent 3G operators. Within this report we refer to the re-assigned spectrum as 2×20MHz rather than 2×19.6MHz, and 2×5MHz rather 2×4.9MHz. Note that the analysis of the impact model is based on 2×19.6MHz and 2×4.9MHz.

> As one of the major mobile communications standards, CDMA is widely deployed in many parts of the world, including Canada, the USA, Japan, Korea and the mainland China. In view of the expiry of the frequency assignment for the IS-95 CDMA network on 19 November 2008, which has been operating in Hong Kong since the early nineteen nineties, the Telecommunications Authority ("TA") decided in April 2007 to assign the necessary radio spectrum in the 850 MHz band for the provision of CDMA2000 service with effect from 20 November 2008 through an open auction.[9]

This requirement precludes refarming this spectrum for any technology standard that is not in the CDMA2000 family, such as 4G LTE services.

In regard to 4G services, apart from the refarmed spectrum in the 1800MHz band, currently there is a total of 2×70MHz paired spectrum in the 2.5–2.6GHz band, and a further 60MHz unpaired spectrum in the 2.3GHz band for the deployment of LTE technology. Recently, CSL and HKT announced the commercial launch of more advanced LTE services. CSL increased by 50% the amount of 1800MHz spectrum used for LTE services in majority of its network, from 2×10MHz to 2×15MHz[10]. In the case of the 2.5–2.6GHz band both CSL[11] and HKT[12] extended their spectrum to 2×20MHz by integrating an additional 2×5MHz awarded in the March 2013 2.5–2.6GHz auction with the 2×15MHz of adjacent spectrum acquired earlier.[13]

There is 80MHz of unpaired spectrum which was assigned to provide mobile services but is still not in use for such purposes: 60MHz in the 2.3GHz band auctioned in March 2012[14], and 20MHz in the 2GHz band awarded in 2001. None of the four 3G licence holders have

9 Office of the Communications Authority (2008), *Frequency Assignment for Provision of CDMA2000 Service*, available at http://tel_archives.ofca.gov.hk/en/tas/mobile/ta20081120.pdf.

10 CSL Limited (2013), *Media release*, available at http://www.hkcsl.com/en/pdf/2013/broadest_4G_FD-LTE_spectrum_ENG.pdf

11 CSL Limited (2013), *Media release*, available at http://www.hkcsl.com/en/pdf/2013/CSL_spectrum_auction_announcement_Eng.pdf.

12 HKT (2013). *Media release*, available at http://www.pccw.com/About+PCCW/Media+Center/Press+Releases?language=en_US.

13 The 2×20MHz in the 2.5–2.6GHz spectrum band is shared by Hutchison and HKT through a joint venture under Genius Brand Limited.

14 30MHz to be deployed by Hutchison in **[**✂....]**CI**, and 30MHz already deployed by China Mobile but still not available for service.

currently deployed any network equipment in the 2GHz band due to lack of commercially available technology. Regarding the 2GHz band, the view of OFCA is that since this unpaired spectrum is not yet a priority band for deployment in the near future, it will be put back into reserve.[15]

Examination of spectrum deployment by technology (Exhibit 2.3) shows that all of the allocated spectrum in the 1.9–2.2GHz band is used to provide 3G services. In addition, it is also the primary band used to provide 3G services. This highlights the importance of the band in serving 3G customers. Incumbent operators with 3G networks therefore have a vested interest in retaining the spectrum currently held. This spectrum is also of great value to MNOs without spectrum for the provision of 3G services (for example, China Mobile) to expand their subscriber bases in this market. Furthermore the ability to refarm this spectrum band for the future provision of 4G services makes it particularly attractive for all parties as it is one of the few bands used in all regional band plans for 4G services. This means that equipment should be readily available and reasonably inexpensive due to the economies of scale inherent in equipment manufacture.

[✂……..……………………………………………………………………………….

15 Commerce and Economic Development Bureau and the Communications Authority (2012), *Second Consultation Paper on Arrangements for the Frequency Spectrum in the 1.9 – 2.2GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services*, available at http://www.coms-auth.hk/filemanager/en/share/cp20121228.pdf.

Note: ....
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Exhibit 2.3: *Hong Kong spectrum deployment by technology [Source: OFCA and operators]*

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Considering MNO spectrum by technology (Exhibit 2.4) China Mobile is the only MNO without spectrum for delivering 3G services. The five MNOs hold frequency bands supporting deployed 2G, and deployed and planned 4G technologies but this is not the case for 3G. In regards to 4G services, China Mobile, CSL and Hutchison together hold around **[✂**…[16]**]CI** of the spectrum allocated or to be allocated for 4G services.

[✂……...…………………………………………………………………………………….

16 This figure includes the 60MHz of unpaired spectrum in the 2.3GHz band from Hutchison and China Mobile which is planned for providing 4G services.

Note: ……
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Exhibit 2.4: *Hong Kong MNO spectrum assignment by technology [Source: OFCA and operators]*

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Available new spectrum

A review of OFCA's Spectrum Release Plan for 2013–2015[17] reveals no indication that new spectrum will be made available in the near future. As detailed in the following paragraphs, there is still some available spectrum that could be potentially assigned in the future but this will not occur by 2016.

17 Office of the Communications Authority (2013), Spectrum Release Plan for 2013-2015, available at http://www.ofca.gov.hk/filemanager/ofca/common/Industry/broadcasting/spectrum_plan2013_en.pdf.

The current working target of the Government to switch off analogue television services is by end 2015, Blocks of spectrum in the 700MHz band may become available for reallocation by that time. A similar situation is currently occurring in many countries throughout the world with the reallocation of spectrum previously used for analogue television (for example, in Australia and the European Union) and is frequently referred to as a ‘digital dividend’. The digital dividend is being consistently allocated internationally for broadband cellular services (4G) and the spectrum rights to this band are anticipated to be extremely valuable. This is due to the superior radio propagation characteristics of the band as well as the internationally harmonised standards for cellular operators in this band.

With the recommendations approved by the ITU, part of the spectrum within the 470–806MHz range, specifically 698–806MHz, has been identified as suitable for mobile broadband services.[18] However, the realisation of any digital dividend in Hong Kong will be subject to the outcome of the frequency coordination with the Mainland authorities and the completion of analogue television switch-off. As was noted above, there is no indication in the Spectrum Release Plan for 2013–2015 that any new spectrum will be assigned over the relevant period, hence it will not be considered for modelling purposes.

An additional 9.7MHz in the 2GHz band could be made available for assignment. The band was listed in the auction of radio spectrum in the 850MHz, 900MHz and 2GHz bands held in February/March 2011 for the provision of public mobile telecommunications services but was not acquired by any bidder. According to the Spectrum Release Plan for 2013–2015[19] the demand for this band will be reviewed by OFCA but no review date has been set. In any event, while there is no commercially available technology for this band, there will be no interest from operators.

Accordingly given the timeframe of our impact modelling we will not take into account any of the potential new spectrum from the digital dividend or the additional spectrum in the 2GHz band.

18 Commerce and Economic Development Bureau (2011), Digital Terrestrial Television – Analogue Switch-off, available at http://www.cedb.gov.hk/ctb/eng/legco/pdf/LegCo_Brief_ASO.pdf.

19 *Ibid.*

MVNOs

Under the terms of the licences for 3G spectrum, 3G MNOs have an obligation to make available 30% of their network capacity in the 1.9–2.2GHz band to third parties (for MVNO arrangements). Although the terms and conditions of MVNO deals are commercially negotiated, we understand from OFCA that there have been no complaints from any parties concerning a lack of availability of spectrum for such arrangements. This implies that sufficient capacity is being made available for MVNOs.

2.2 Market overview

2.2.1 The Hong Kong mobile market

Hong Kong's telecommunication sector has been liberalised since the 1990s with no foreign ownership restrictions. With a high density population in an urbanised environment and high penetration rates, Hong Kong has retained a pro-competition policy and pro-market approach resulting in one of the most competitive markets in the world[20] and delivering significant consumer benefits.

Hong Kong has one of the world's highest mobile penetration rates, with 231 mobile subscriptions per 100 inhabitants, representing over 16.5 million mobile service subscriptions.[21] The penetration rate has been increasing steadily in the last few years and simultaneously, there has been a rapid increase in mobile data traffic (Exhibit 2.5). In December 2012, the monthly mobile data traffic usage in Hong Kong was recorded as

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20 ITU (2011), *ITU News September 2011. Hong Kong China, some valuable pointers*, available at http://www.itu.int/net/itunews/issues/2011/07/29.aspx.

21 Office of the Communications Authority website, *Key Communications Statistics,* available at http://www.ofca.gov.hk/en/media_focus/data_statistics/key_stat/index.html, accessed 26 August 2013

greater than 7PB with an average of over 760MB per 2.5G/3G/4G mobile subscription per month.[22]

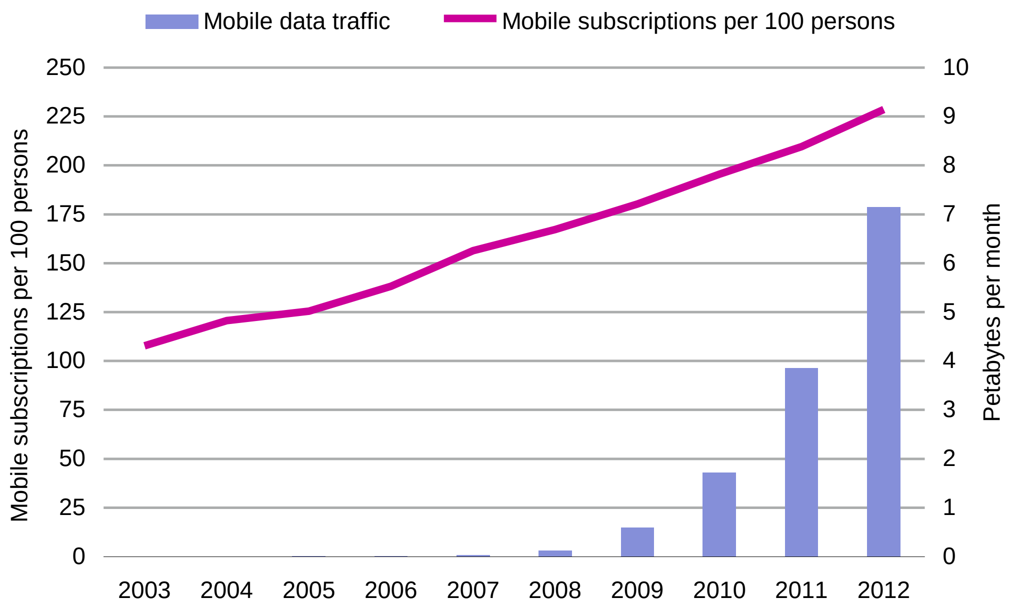


Exhibit 2.5: *Hong Kong mobile data traffic and penetration [Source: OFCA]*

The market is highly competitive, having five MNOs: China Mobile Hong Kong Company Limited, CSL Limited, Hong Kong Telecommunications (HKT) Limited, Hutchison Telephone Company Limited and SmarTone Mobile Communications Limited,[23] and currently fifteen licensed MVNOs (Exhibit 2.6).[24]

22 Office of the Communications Authority website, *Key Communications Statistics,* available at http://www.ofca.gov.hk/en/media_focus/data_statistics/key_stat/index.html, accessed 25 March 2013.

23 Office of the Communications Authority (2012), *Hong Kong : The Facts,* available at http://www.gov.hk/en/about/abouthk/factsheets/docs/telecommunications.pdf.

24 Communications Authority website, *Services-Based Operator (SBO) Licences Enquiry,* available at http://www.coms-auth.hk/en/licensing/telecommunications/carrier/index.html.

Name of licensee	*Licence No.*	*Class 3 service*			
		MVNO services	*ETS*	*IVANS IAS*	*IVANS other than IAS*
China Motion Telecom (HK) Ltd.	908	✓			
China Unicom (Hong Kong) Operations Limited	922	✓	✓	✓	
China-Hongkong Telecom Limited	951	✓	✓		
CITIC Telecom International Limited	1015	✓	✓	✓	✓
Telecom Digital Mobile Ltd.	1097	✓			
IMC Networks Limited	1210	✓			
Technical Data Limited	1416	✓			
New World Mobility Limited	1445	✓			
Truphone (Hong Kong) Limited	1568	✓	✓		
Telekomunikasi Indonesia International (HongKong) Limited	1604	✓			
Future Power International Limited	1609	✓	✓		
Airstar Telecom Holding Limited	1633	✓			
Delcom (HK) Limited	1650	✓			
Amoeba Limited	1655	✓			
GreenRoam Limited	1660	✓			
Total number of licence(s)		15	5	2	1

MVNO – Mobile Virtual Network Operator

ETS – External Telecommunications Services

IVANS – International Value-Added Network Services

IAS – Internet Access Services

Exhibit 2.6: *Services-Based Operator (SBO) licences as at July 2013 [Source: OFCA]*

2.2.2 Relative performance of mobile market operators

In terms of overall subscription numbers, all of the MNOs appear to have enjoyed increases over the last year:

- CSL's mobile subscriptions grew by 321 000 to a total of 3.8 million, an increase of 0.9% in the period ending December 2012.[25]
- Hutchison's total mobile subscription base in Hong Kong and Macau increased 8% to over 3.7 million, as at 31 December 2012[26]. This included a total of 2.0 million postpaid subscriptions. 3G and 4G subscriptions represented 94% of the postpaid segment, with smart devices representing 58% of 3G and 4G postpaid subscriptions.
- In 2012[27], HKT's mobile business experienced a 7% growth in subscriptions compared with 2011, resulting in 1 645 000 subscriptions by the end of 2012. The number of post-paid subscriptions also increased by 7% to 1 013 000.
- SmarTone's subscriptions increased by 7% (annual growth) to 1.738 million as at December 2012, according to its 2012-2013 interim report[28]. This reflects a 9% annual growth in mobile subscriptions for both postpaid and prepaid services.

[✂…… ………………………………………………………………………………………]CI

Analysis of the recent financial results of the incumbent MNOs indicates revenue growth is being driven partly by expansion of the mobile data and device market. This information on market trends in smart device uptake and usage is helpful for scoping the potential future market for data services in Hong Kong (see Section 4.1).

25 Telstra Corporation Limited (2013), *Directors' report for the half-year ended 31 December 2012*, available at http://www.telstra.com.au/abouttelstra/investor/financial-information/financial-results/index.htm.

26 Hutchison Telecommunications Hong Kong Holdings Limited (2013), *2012 annual report*, available at http://www.hthkh.com/eng/ir/reports.php.

27 Hong Kong Telecommunications (HKT) Limited (2013), *Annual report 2012*, available at http://www.hkt.com/About+HKT/Investor+Relations/Financial+Results?language=en_US.

28 SmarTone Telecommunications Holdings Limited (2013), *Interim report 2012/13*, available at http://www.smartoneholdings.com/jsp/smc_investor/financial_reports/english/index.jsp.

CSL: increasing customer numbers

For the second half of 2012 CSL's revenue rose by 13.8% to HKD3 978 million in comparison with the same period in 2011. This increase was driven by strong customer growth with the introduction of new device bundles and competitive mobile plans.

Hutchison: strong demand for mobile data services and hardware

Turnover for Hutchison's mobile business increased by 19% to HKD12 383 million as a result of high demand for smart devices. Mobile service revenue in 2012 (HKD5 482 million) was comparable to that in 2011, with an increase of 12% in data revenue offset by a 13% decrease in voice revenue. Data services continued to increase in 2012 and accounted for 59% of total service revenue.

HKT: growing customer base and improving ARPU

HKT's mobile business delivered high growth with a 25% annual increase in total mobile revenue to HKD2 466 million for 2012. Mobile service revenue also increased by 25% in relation to 2011 due to a growing customer base and an improvement in ARPU. Mobile data revenue increased by 55% in comparison to 2011, and represented 73% of mobile service revenue for the 2012 year.

SmarTone: burgeoning demand for smart devices

SmarTone's total revenue increased by 16% to HKD5 888 million, with a 2% growth in service revenue, compared to the same period in 2011. An increase of handset and accessory sales of 34% was achieved for the last half of 2012 in comparison to the same period in 2011, mainly driven by the popularity of smart devices, and both sales volume and average unit selling price increases.

2.3 Visitors to Hong Kong

In 2012, there were 48.6 million visitors to Hong Kong, of which nearly 72% were from Mainland China. Just over half (51.1%) of all visitors stayed for less than a day, with the remainder staying on average 3.5 days[29]. The Hong Kong Tourism Board predicts further

29 Hong Kong Tourism Board (2013) *Hong Kong Tourism Board Work Plan for 2013-14*.

growth in 2013, reaching 51.9 million visitors, of which 73% will be from Mainland China (Exhibit 2.7).

Exhibit 2.7: *Visitor arrivals, 2010 to 2013 [Source: Hong Kong Tourism Board]*

In order for visitors to use their own mobile handsets when in Hong Kong, it is essential that the combination of technology and frequency bands under which the handset operates is compatible with at least one mobile network in Hong Kong. If this is not the case, then the visitor would need to either purchase or lease a suitable handset for the duration of their stay.

In general, there is a degree of international standardisation across many markets; however it is impractical for MNOs to support all possibilities of technology and frequency bands. Given the dominance of Mainland China as a source of visitors, it may be appropriate to consider the implications of this market segment.

The mobile market in Mainland China is still dominated by 2G services, with 3G having only a relatively modest – albeit rapidly growing – share of subscriptions (Exhibit 2.8). In the two years from 2010, 3G subscriptions have increased from just 5.6% of total subscriptions to 21%. Over the period to 2018 we would expect increasing substitution of 2G with 3G services; however this will be driven by strategic business decisions of the operators. Indications from operator financial reports are that there are strategies to grow mobile data revenues, which will require consumers to upgrade their handsets to 3G or LTE. This may also require operators to expand 3G coverage in Mainland China, as currently – according to operator financial reports – this appears to be mostly limited to urban areas.

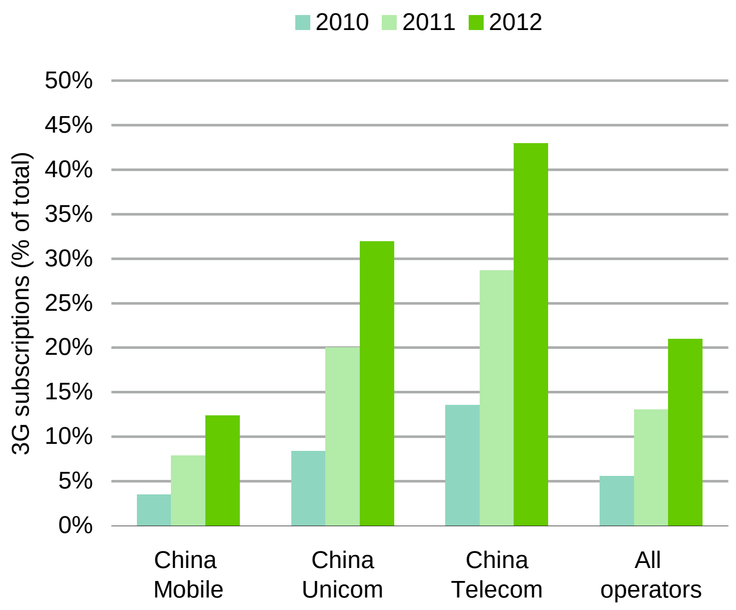


Exhibit 2.8:
3G subscriptions as a proportion of total mobile subscriptions for Mainland Chinese operators, 2010 to 2012 [Source: operator financial reports]

Traffic information provided by the Hong Kong operators for use in the impact model is inclusive of the traffic generated by international visitors. Therefore the impact model allows for the effect of visitor traffic.

3 Analysis of scenarios

If Option 3 is to be adopted to re-assign spectrum in the 1.9–2.2GHz band different outcomes are possible from the re-auction of the 2×20MHz of spectrum:

- **Status quo**: no change of spectrum assignment of all the four incumbent 3G operators ("base case").
- **Partial failed incumbent acquisition**: one, two or three of the 3G incumbents fail to acquire any re-auctioned spectrum.
- **Existing MNO acquisition; no incumbents**: the MNO without 3G spectrum acquires the 2×20MHz of re-auctioned spectrum and none of the incumbents acquire any.
- **New entrant acquisition; no incumbents**: one or more new entrants acquire the 2×20MHz re-auctioned spectrum and none of the incumbents acquire any.
- **Existing MNO and new entrant acquisition; no incumbents:** the MNO without 3G spectrum and one or more new entrants acquire the 2×20MHz re-auctioned spectrum and none of the incumbents acquire any.

The second scenario – where one or more of the incumbent operators fail to re-acquire their current holdings of the re-auctioned spectrum – encompasses a number of different possible outcomes, while there are two possible outcomes under the fourth (new entrant) scenario (Exhibit 3.1 and Exhibit 3.2). Note also that within each sub-scenario under the second scenario if we identify each of the operators by name, many further scenarios would be possible. For example, in one scenario an operator obtains 2×20MHz while the other incumbent operators obtain 2×10MHz. Since the former operator could be any one of the four incumbent operators, there are four possible permutations within this sub-scenario.

In developing the scenarios, we have assumed that each incumbent operator will exercise its right of first refusal and keep two-thirds of its spectrum (i.e. 2×10MHz). As one-third of each operator's spectrum (i.e. 2×5MHz) will be re-auctioned, it is also assumed that each operator will not acquire more than 2×10MHz spectrum in the auction.

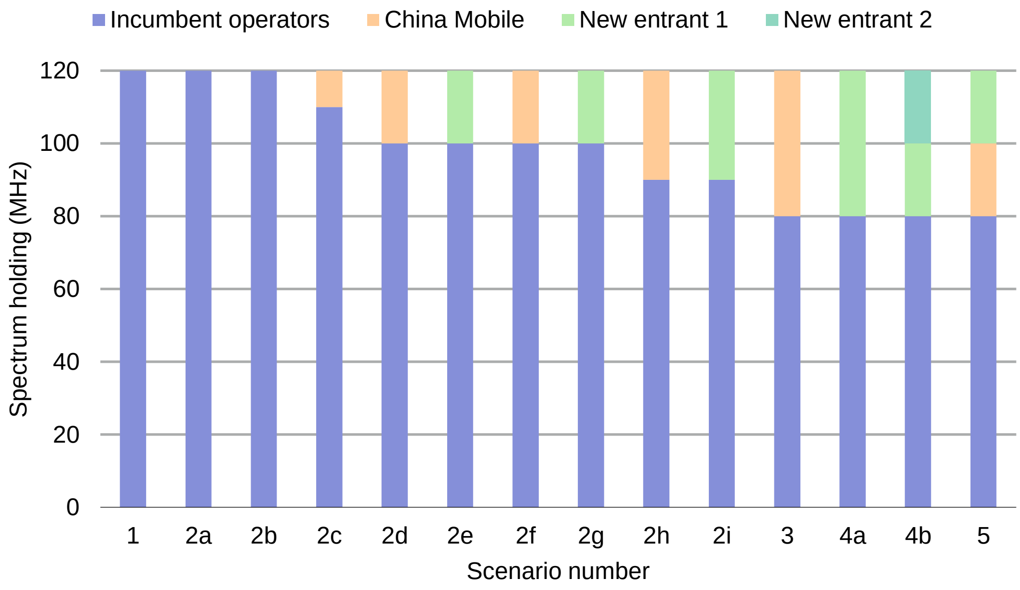


Exhibit 3.1: *Spectrum holdings of the operators under different scenarios [Source: Network Strategies]*

Scenario name	*Scenario number*	*Incumbent operators*	*MNO without 3G spectrum*	*New entrants*
Status quo	1	2×15MHz, 2×15MHz, 2×15MHz, 2×15MHz		
Partial failed incumbent acquisition	2a	2×10MHz, 2×15MHz, 2×15MHz, 2×20MHz		
	2b	2×10MHz, 2×10MHz, 2×20MHz, 2×20MHz		
	2c	2×10MHz, 2×15MHz, 2×15MHz, 2×15MHz	2×5MHz	
	2d	2×10MHz, 2×10MHz, 2×15MHz, 2×15MHz	2×10MHz	
	2e	2×10MHz, 2×10MHz, 2×15MHz, 2×15MHz		2×10MHz
	2f	2×10MHz, 2×10MHz, 2×10MHz, 2×20MHz	2×10MHz	
	2g	2×10MHz, 2×10MHz, 2×10MHz, 2×20MHz		2×10MHz
	2h	2×10MHz, 2×10MHz, 2×10MHz, 2×15MHz	2×15MHz	
	2i	2×10MHz, 2×10MHz, 2×10MHz, 2×15MHz		2×15MHz
Existing MNO acquisition; no incumbents	3	2×10MHz, 2×10MHz, 2×10MHz, 2×10MHz	2×20MHz	
New entrant acquisition; no incumbents	4a	2×10MHz, 2×10MHz, 2×10MHz, 2×10MHz		2×20MHz
	4b	2×10MHz, 2×10MHz, 2×10MHz, 2×10MHz		2×10MHz, 2×10MHz
Existing MNO and new entrant acquisition; no incumbents	5	2×10MHz, 2×10MHz, 2×10MHz, 2×10MHz	2×10MHz	2×10MHz

Exhibit 3.2: *Spectrum holdings of the incumbent operators, the MNO without 3G spectrum and new entrants for different scenarios [Source: Network Strategies]*

So which of the above scenarios would most likely occur? While it is clear that the four incumbent operators and the MNO without 3G spectrum all wish to retain or acquire 3G spectrum, it is uncertain whether any potential new entrants will emerge. As far as we are aware no potential new entrant has announced a desire to acquire this spectrum at auction. Had there been such interest we would have expected the potential new entrant to participate in submissions during the Consultations and this has not occurred. Furthermore there would be significant market entry barriers for a complete newcomer, including the need to acquire sites rapidly, significant capital investment and lack of an existing customer base. Finally, from a business point of view, it would probably be optimal for a new entrant either to acquire an incumbent MNO or apply for an MVNO licence than to bid for 3G spectrum.

Entry barriers are lower for an existing MVNO than a new entrant. Consequently we considered whether any current holders of MVNO licences are likely to bid for 3G spectrum by examining past participation of MVNOs in recent spectrum auctions in Hong Kong together with public company information and statements. This examination reveals only one example of an MVNO as a qualified bidder (Exhibit 3.3). China Unicom was a qualified bidder for the 2013 2.5–2.6GHz auction. However it failed to acquire any spectrum while China Mobile, CSL, SmarTone and Genius Brand (a joint venture between Hutchison and Hong Kong Telephone) all acquired spectrum in that auction.

Qualified bidders	*Successful bidder?*	*Lot size (MHz)*	*Lower band*	*Upper band*	*Amount paid (HKD million)*
2.5–2.6GHz (March 2013)					
China Mobile HK	✓	2×5	2530-2535	2650-2655	300.00
China Unicom (HK)					
CSL	✓	2×5	2535-2540	2655-2660	310.00
Genius Brand	✓	2×5	2515-2520	2635-2640	290.00
SmarTone	✓	2×5	2520-2525	2640-2645	330.00
		2×5	2525-2530	2645-2650	310.00
2.3GHz (February 2012)					
21 ViaNet	✓	30	2300-2330		150.00
China Mobile	✓	30	2330-2360		170.00
HKT					
Hutchison	✓	30	2360-2390		150.00
850MHz, 900MHz and 2GHz (March 2011)					
China Mobile HK					
CSL					
HK Broadband Network					
HKT					
Hutchison	✓	2×5	832.5-837.4	877.5-882.5	875.00
SmarTone	✓	2×5	885-890	930-935	1077.00
Mobile TV Radio Spectrum Licensing (June 2010)					
China Mobile HK	✓	8	678-686		175.00
City Telecom (HK)					
HKT					
1800MHz (June 2009)					
China Mobile HK	✓	2×0.8	1783.3-1784.1	1878.3-1879.1	7.32
		2×0.8	1782.5-1783.3	1877.5-1878.3	7.80
HKT	✓	2×0.8	1780.9-1781.7	1875.9-1876.7	8.22
		2×0.8	1780.1-1780.9	1875.1-1875.9	8.22
SmarTone	✓	2×0.8	1784.1-1784.9	1879.1-1879.9	7.13
		2×0.8	1781.7-1782.5	1876.7-1877.5	7.41

Exhibit 3.3: *Qualified bidders and results from recent Hong Kong spectrum auctions [Source: OFCA]*

Qualified bidders	*Successful bidder?*	*Lot size (MHz)*	*Lower band*	*Upper band*	*Amount paid (HKD million)*
Broadband Wireless Access (January 2009)					
China Mobile HK	✓	6×5	2555-2570		494.70
			2675-2690		
CSL	✓	6×5	2540-2555		523.00
			2660-2675		
Genius Brand	✓	6×5	2500-2515		518.00
			2620-2635		
HK Broadband Network					
SmarTone					

Genius Brand is a joint venture between Hutchison and HKT.

Exhibit 3.3 (cont): *Qualified bidders and results from recent Hong Kong spectrum auctions [Source: OFCA]*

Despite its failure at auction, the fact that China Unicom participated may be interpreted as an indication that MVNOs could potentially be interested in seeking acquisition of spectrum in a future 3G auction. However this must be balanced against other publicly available information from MVNOs. In particular we note information provided in the most recent interim report of China Motion Telecom[30], another Hong Kong MVNO until its November 2012 acquisition by VelaTel. The report states that the company decided to divest its entire MVNO operations in Hong Kong as a result of competitive pressures in the market and the necessity for substantial further investment to remain competitive.

Despite growing demand from international travellers which did allow for some MVNO business expansion, China Motion also noted changes in Hong Kong consumer usage behaviour which had adversely affected its MVNO business including:

- rapid growth in social networking applications which was reducing usage of voice (with over 9% decline in voice minutes compared to the previous year) and short

30 China Motion Telecom International Limited (2013), *Interim Report 2012/13*.

message services (particularly with respect to cross-border communications). At the same time a partial offset from increased usage of data services was noted.

- the launch of popular smartphone devices affecting customers' choice of service, particularly where MVNOs could not offer popular models and / or where some of the devices were heavily subsidised by MNOs.

The experience of China Motion indicates that while in the future there may be attractive niche opportunities for MVNOs, the scope for competing with the incumbent MNOs is limited, without significant further investment. As such, on reviewing available company information of current Hong Kong MVNOs it appears unlikely that many would be in a position to undertake investment of the scale required to become MNOs. Many current MVNOs are either relatively small and / or limited in the scope of their existing operations.

Our review of the likelihood of new entry by existing MVNOs leaves only China Unicom as a real prospect (assuming that VelaTel has not revised the expectations of its new acquisition). However China Unicom has made no public statements to indicate that it has an interest in bidding for spectrum in the 1.9–2.2GHz band.

We conclude that on balance it is unlikely that there will be substantial interest from new entrants in the 3G spectrum to be auctioned under Option 3 with the possible exception of China Unicom. Thus we conclude that the following scenarios should be excluded from further analysis: 2e, 2g, 2i, both 4a and 4b, and 5.

The scenarios that remain are 2a, 2b, 2c, 2d, 2f, 2h and 3. We believe that Scenario 3 – the MNO without 3G spectrum acquiring the entire auctioned spectrum – is the least likely of these remaining scenarios. The outcome of any spectrum auction will ultimately depend on the price, and each individual MNO's business cost-benefit analysis. From a technical perspective an assignment exercise of 2×20MHz would be more than any other single MNO currently uses in the 1.9–2.2 GHz spectrum band. Naturally the MNO without 3G spectrum may wish to acquire 2×20MHz for strategic or competitive reasons; however such a scenario would leave all of the other MNOs at a competitive disadvantage. As such it will be in the interests of the other MNOs either to retain or increase the amount of spectrum they currently hold. This diminishes the likelihood of Scenario 3. Although we do not consider this scenario highly likely, at the same time it does represent an 'extreme' case in which all existing incumbents lose their 2×5MHz re-auctioned spectrum. As such the scenario is useful in providing an extreme case reference point.

One reasonable outcome is that the incumbent operators strive to retain all of their existing holdings, and that the auction process results in a rearrangement of existing holdings with the MNO without 3G spectrum unsuccessful in obtaining any lots (scenarios 2a and 2b). Given that each of the largest two MNOs have about 24% of the total allocated mobile spectrum and around the same percentage of subscriptions, the smaller MNOs have a greater proportion of the spectrum compared with their proportion of subscriptions. This might imply that the spectrum would be most valuable to the larger MNOs given that they are servicing more subscriptions with essentially less spectrum. However one of the smaller operators (SmarTone) might equally desire a larger holding, given its focus on high-end customers requiring high quality reliable services. We conclude that there will be strong motivation amongst the incumbents to retain existing holdings and at least one operator may seek to increase its holdings. On this basis we consider scenario 2a more likely than 2b, but both are considered likely scenarios.

The MNO without 3G spectrum **[✂**…….. ……………………………………………………………….**]CI** may regard 2×10MHz to be optimal (scenario 2d or 2f). Of these two scenarios we regard 2d as more likely than 2f on the basis that the strong desire of all incumbent operators to maintain existing holdings will result in at least two maintaining 2×15MHz. In Scenario 2f three incumbent operators lose 2×5MHz while one increases its holdings to 2×20MHz. Given its existing holdings and assuming that it is not motivated to acquire spectrum for strategic reasons alone an acquisition by the MNO without 3G spectrum of 2×15MHz also seems less likely (scenario 2h). Thus in our view the other two likely scenarios are 2c and 2d.

We thus conclude that the four likely scenarios are Scenarios 2a, 2b, 2c and 2d. These four scenarios as well as Scenario 3, as an ‘extreme case’ (albeit unlikely) scenario, have been selected for further modelling analysis.

4 Demand forecasts for Hong Kong

4.1 Global and regional trends

According to OFCA's projections, total mobile data traffic will increase six-fold from 2012 to 2016,[31] reaching around 400PB per year by 2016 in Hong Kong. In the submissions to the Second Consultation, a number of respondents argued that OFCA had under-estimated the traffic growth and referenced Cisco projections. Cisco's latest projections expect the total data traffic to increase eight-fold globally and eleven-fold in the Asia Pacific region over the period 2012–2016.[32] Note that industry sources have been reducing their projected growth rates for mobile data traffic – over the past three years Cisco's projected Asia Pacific annual growth rates have fallen from 102% to 76%. Even though Ericsson's forecasts have been less bullish than those of Cisco, its projected global annual growth rates fell from 60% to 50% over two years (Exhibit 4.1).

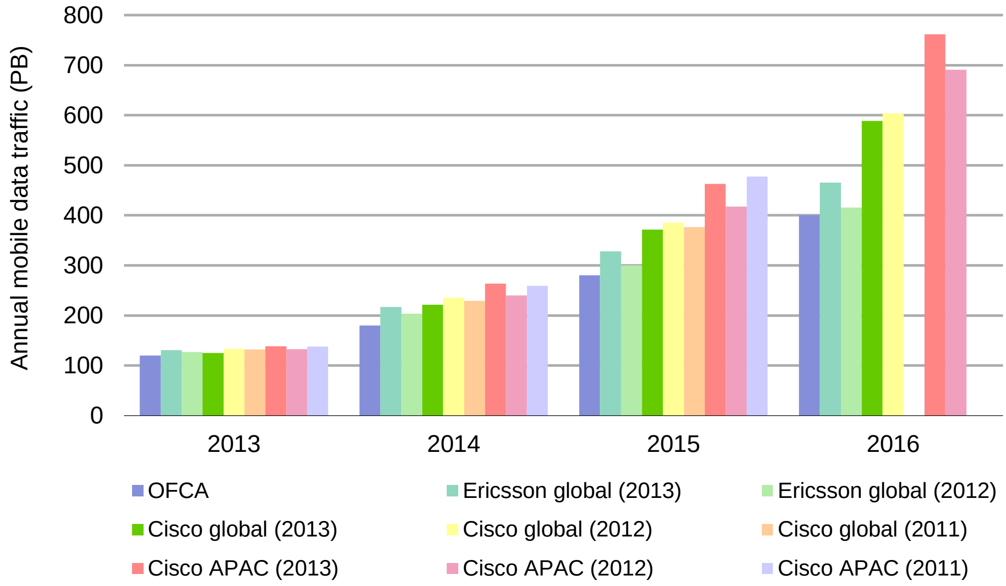
31 Commerce and Economic Development Bureau and the Communications Authority (2012), *Second Consultation Paper on Arrangements for the Frequency Spectrum in the 1.9 – 2.2GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services*, available at http://www.coms-auth.hk/filemanager/en/share/cp20121228.pdf.

32 Cisco (2013), *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017*, available at http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf.

Name	*Release year*	*Period covered*	*Projected compound annual growth rate (%)*
Ericsson mobility report global	2013	2012-2018	50%
Cisco VNI global	2013	2012-2017	66%
Cisco VNI APAC	2013	2012-2017	76%
Ericsson mobility report global	2012	2011-2017	60%
Cisco VNI global	2012	2011-2016	78%
Cisco VNI APAC	2012	2011-2016	84%
Cisco VNI global	2011	2010-2015	92%
Cisco VNI APAC	2011	2010-2015	102%

Exhibit 4.1: *Projected global and Asia Pacific (APAC) mobile data growth rates [Source: Cisco and Ericsson]*

Network Strategies applied the year on year growth rates for the different projections (outlined in Exhibit 4.1) to a common base of the Hong Kong mobile data traffic in 2012. The resulting forecasts are compared in Exhibit 4.2. As can be seen, outcomes differ dramatically for the different growth assumptions.



Note: series specify the source of the underlying growth rate and the year in which the projected growth rate was released.

Exhibit 4.2: *Projections of total mobile data traffic for Hong Kong based on growth rates from various sources [Source: Network Strategies]*

4.2 Demand projections for the impact model

We developed a separate forecasting model to project the demand-side of the impact model. This forecasting model was used primarily as a cross-check for the traffic information that was supplied by the operators, but also to address any gaps in that traffic information.

Operators provided busy hour data traffic projections to Network Strategies. This information is used by the impact model to calculate the network demand in Mbit/s during the busy hour. Operators provided sufficient busy hour data traffic projections, however little information was received on voice and SMS traffic. Accordingly the forecasting model was used to derive per-subscription usage projections for voice and SMS only. These projections, applied to the subscription figures provided by the operators, were then used to forecast monthly voice and SMS traffic which we then converted into busy hour voice and SMS projections for use in the impact model.

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The forecasting model utilises as much operator-provided data as possible. MNOs provided subscription projections to Network Strategies and the aggregate of this data is illustrated in Exhibit 4.3. Overall the subscriber growth trend is strong, reflecting uptake of multiple subscriptions by consumers. Subscriptions of 3G services continue to increase, while by 2018 it is anticipated there will be minimal 2G subscriptions.

Total subscription projections form a key input for the calculation of monthly voice traffic, together with per-subscription usage. It should be noted that the subscription data from the operators was lower than OFCA data on subscriptions, which we understand was also supplied by operators. We believe this is most likely due to differing definitions of 'active' subscribers. Nevertheless this does not affect the model results substantially as the use of per-subscription traffic (to derive voice and SMS demand) is appropriately scaled for this lower base.[33]

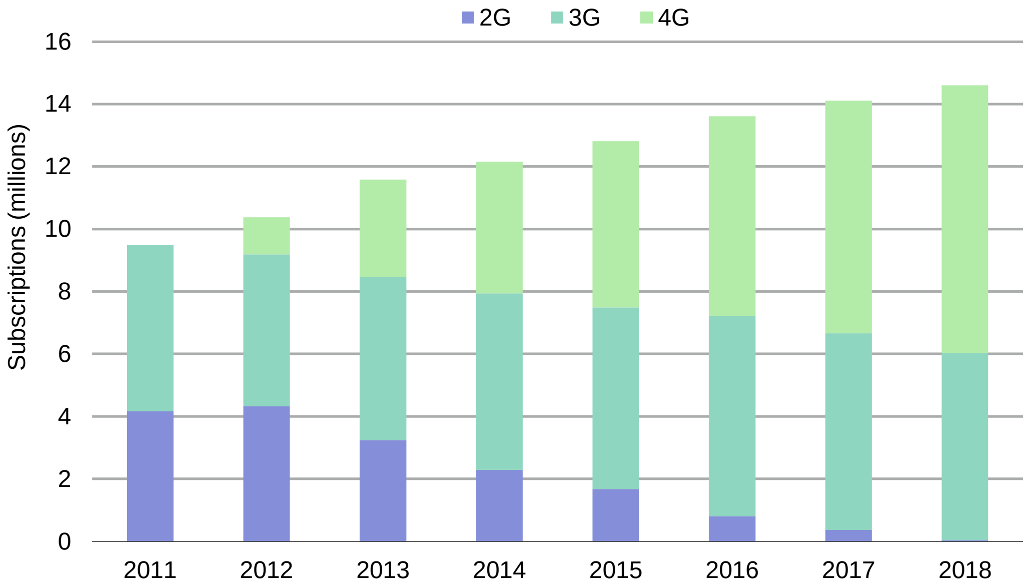

Exhibit 4.3: *Projections of mobile subscriptions split by technology [Source: operators and Network Strategies]*

The operators supplied the total active subscriptions as well as the number of subscriptions for 2G, 3G and 4G networks.

33 If a higher subscription base had been used, the per-subscription traffic would be lower, however the total traffic (multiplying the per-subscription traffic by total subscriptions) would be the same.

The voice projections indicate a static demand for voice over the modelling period (Exhibit 4.4). An increased proportion of the voice traffic will be carried on 4G networks, particularly after the assumed network upgrade to LTE-A in 2015, which allows voice over LTE services (prior to this the impact model assumes that all 4G voice traffic is carried on the 3G network). A slight decrease in voice traffic on 3G networks is expected over the modelling period.

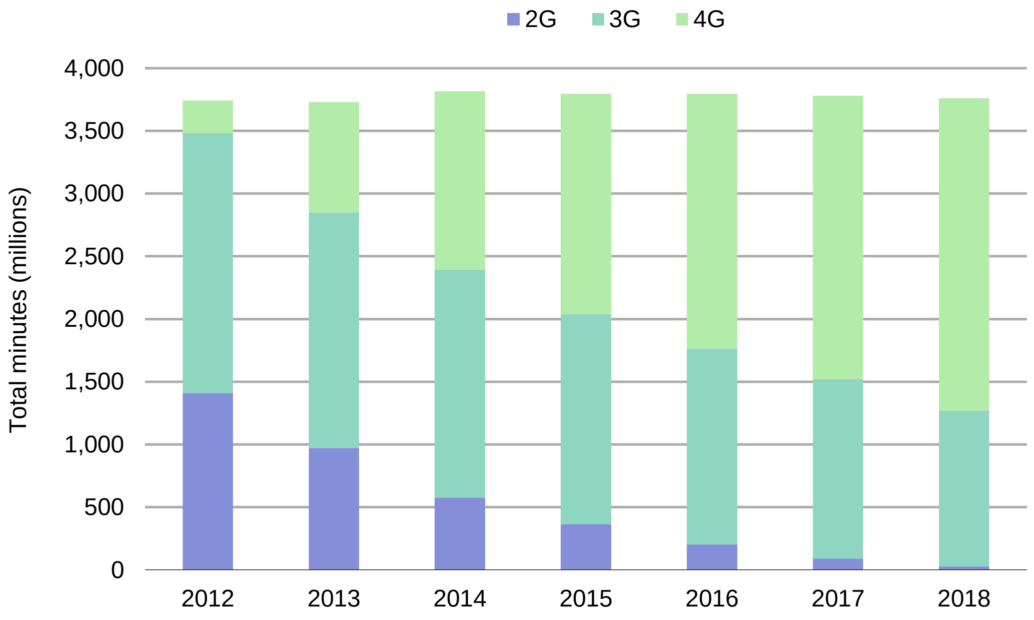

Exhibit 4.4: *Annual voice traffic forecast split by technology [Source: operators and Network Strategies]*

SMS projections are included in the impact model for completeness, although SMS is not expected to have any implications with regard to quality of service for customers. This is partly because SMS is a 'best effort' service and therefore does not affect network dimensioning materially. In addition SMS usage is expected to decline (Exhibit 4.5) as customers increasingly use alternative instant messaging services.

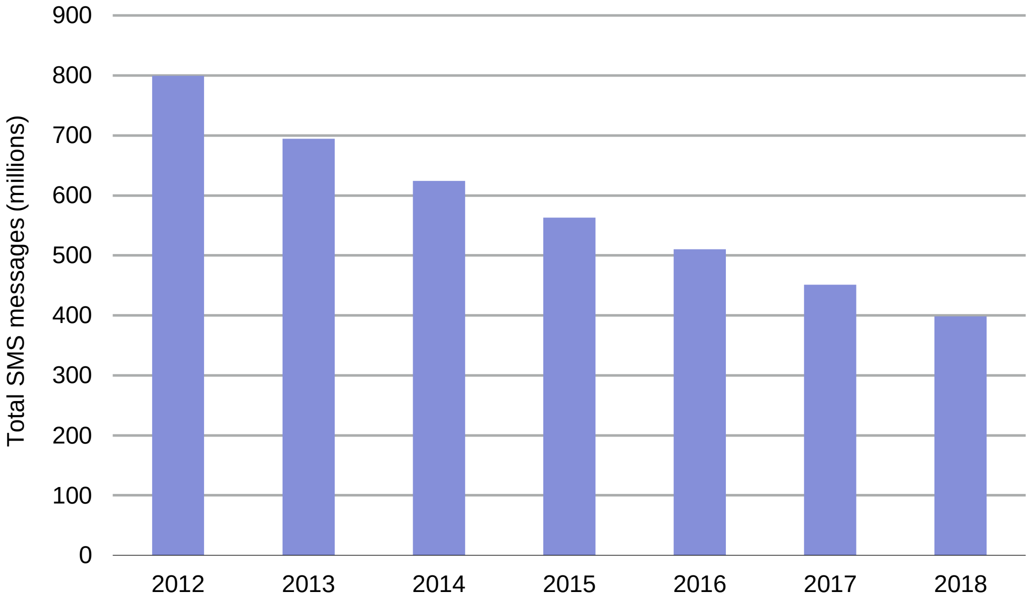

Exhibit 4.5: *Annual SMS traffic forecast [Source: operators and Network Strategies]*

While the impact model utilises projected busy hour data traffic – supplied by the operators – we have converted this busy hour traffic to annual traffic (Exhibit 4.6) solely for cross-checking with projections of data traffic from other sources. The conversion was based on assumptions using data provided by operators, publicly available sources and Network Strategies internal databases.

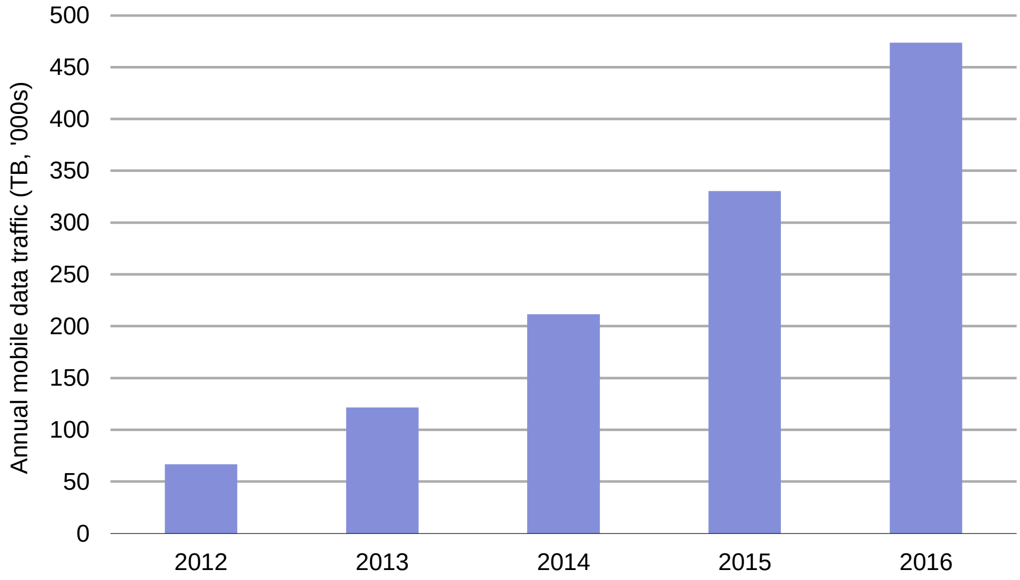

Exhibit 4.6: *Annual total data traffic forecast [Source: operators and Network Strategies]*

The mobile data traffic forecast shows a seven-fold increase from 2012 to 2016. Note that it is highly sensitive to the underlying assumptions for converting busy hour traffic to monthly traffic. We have used benchmark assumptions for the conversion, as the operators did not provide us with this information; however we note that these assumptions can vary between operators.

5 Mitigation strategies

The expected increase in traffic demand requires a significant expansion of total network capacity to avoid congestion, slow downloads and interrupted data sessions.[34] As shown in Exhibit 5.1, the capacity depends on available spectrum, spectral efficiency of the wireless technology deployed and number of cell sites.[35] Hence, the strategies available to increase network capacity are:

- acquire additional spectrum
- refarm existing spectrum
- improve spectrum efficiency
- increase number of cell sites
- offload to WiFi networks.

Generally, if two or more strategies are implemented simultaneously, multiple gains in total capacity can be achieved to satisfy increased demand.[36]

Note that assessing the cost of mitigation strategies was outside the scope of this study.

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34 Rysavy Research (2010), *Mobile Broadband Capacity Constraints And the Need for Optimization*, available at http://www.rysavy.com/Articles/2010_02_Rysavy_Mobile_Broadband_Capacity_Constraints.pdf.

35 Federal Communications Commission (2010), *Mobile broadband: the benefits of additional spectrum,* available at http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf.

36 GigaOM website (2012), *Small networks mean big capacity gains,* available at http://gigaom.com/2012/10/18/as-nokia-siemens-shrinks-the-4g-network-its-prospects-grow/.

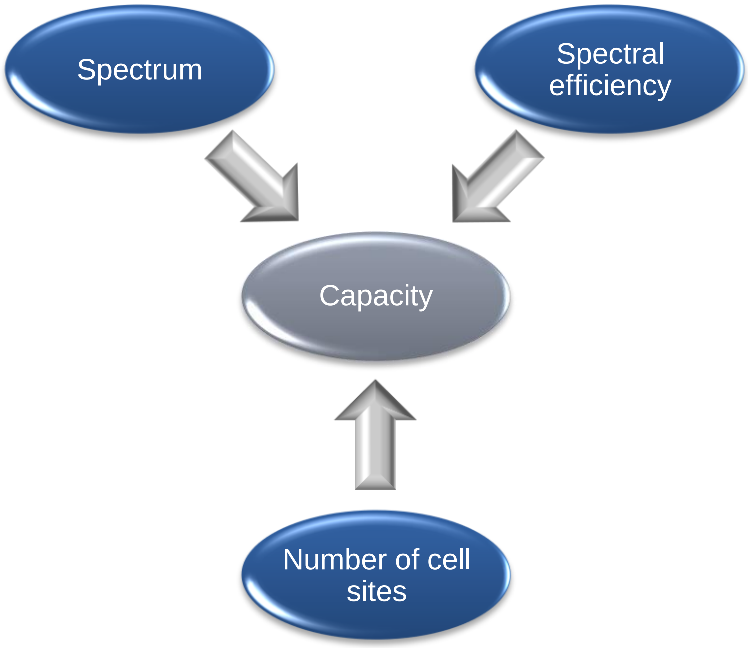

Exhibit 5.1: *Factors affecting capacity [Source: Network Strategies]*

5.1 Acquire additional spectrum

One strategy to increase capacity is to acquire additional spectrum. Spectrum is a limited resource and although new spectrum bands are being released for mobile services, the demand for services is expected to grow at a more rapid rate than new spectrum can be made available.[37] No new spectrum is expected to become available to Hong Kong operators over our modelling period.

Spectrum sharing is a new approach whereby multiple operators can share the same spectrum band to provide service.[38] This can be considered as acquiring additional

37 Real Wireless Ltd. (2011), *4G Capacity Gains,* available at http://stakeholders.ofcom.org.uk/binaries/research/technology-research/2011/4g/4GCapacityGainsFinalReport.pdf.

38 Qualcomm (2012), *1000x: More Spectrum—Especially for Small Cells,* available at http://www.qualcomm.com/media/documents/files/wireless-networks-1000x-more-spectrum-especially-for-small-cells.pdf.

spectrum but without having exclusive rights.[39] The operators with excess capacity can share their spectrum with other operators who do not have enough spectrum to support all their demand. Thus, spectrum sharing can eventually result in more efficient overall use of spectrum. However, this is not a viable strategy to mitigate the effects of re-assignment in the 1.9–2.2GHz band in Hong Kong as the 3G spectrum is already highly utilised. In addition, spectrum sharing also has some technological and regulatory challenges:

> Spectrum sharing will entail a multi-faceted process that requires identifying what types of systems will be shared and how, determining the market for shared systems, developing specifications and standards to allow sharing including spectrum coordination systems, modifying primary and secondary systems to integrate with the new sharing architectures, and developing infrastructure and devices to implement the sharing. In addition, there may also need to be new spectrum-market systems. [40]

Hence Network Strategies believes that acquiring additional spectrum is not a feasible option for operators in this analysis.

5.2 Refarm existing spectrum

The spectrum in the operators' existing allocations may be refarmed by upgrading the technology that utilises the spectrum bands. For example, operators are currently reducing the amount of spectrum deployed for 2G services as demand for these services declines, with the shift to 3G and 4G services. Operators then re-use those cleared bands for the provision of 3G and 4G services.

With the exception of the frequencies 825–832.5MHz paired with 870–877.5MHz, which is restricted to the use of CDMA2000 technology for the provision of 3G services, there are no regulatory barriers to refarming the remaining spectrum bands in Hong Kong.

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39 Radio Access and Spectrum (2012), *A white paper on spectrum sharing,* available at http://www.ict-qosmos.eu/fileadmin/documents/Dissemination/White_Papers/RAS_Cluster_white_paper.pdf.

40 Rysavy Research (2012), *Spectrum Sharing - The Promise and The Reality,* available at http://www.rysavy.com/Articles/2012_07_Spectrum_Sharing.pdf.

Operators have already refarmed spectrum – in the 850–900MHz and 1800MHz bands – for their 3G and 4G networks. Currently about 57% of the 850–900MHz band is being used to provide 3G services and around 60% of the 1800MHz band for 4G services.

The 2G, 3G and 4G spectrum bands are designated for specific network technology to serve 2G, 3G and 4G devices respectively. As such, the networks, which may be operated by a single MNO, are separate in that the lower generation devices cannot be served with the higher generation technology, for example 3G devices cannot be served on the 4G network (though backward compatibility is possible, for example the 3G network can serve 4G devices). Consequently, even though refarming spectrum from 3G (or 2G) to 4G can increase the capacity of the spectrum – as 4G is more spectrally efficient – it will reduce the spectrum available for the existing 3G (or 2G) devices. This may lead to congestion on individual networks depending on the distribution of the mobile traffic. As the demand data used in the model was based upon information supplied by the operators, it may already include some implicit assumptions regarding the migration of 2G and 3G customers to 4G. As shown in Section 7.1, there is significantly more capacity than demand on the 4G networks. Therefore if operators implemented strategies to accelerate migration of 3G customers to 4G the impact on the 3G hotspot network discussed in Section 7.1 could be reduced.

In this study, Network Strategies has used 2G, 3G and 4G traffic values and refarming plans provided by the operators. Some operators have indicated that they intend to refarm 2G and/or 3G spectrum to 4G in the 850–900MHz and 1800MHz bands (as shown in Exhibit 5.2 and Exhibit 5.3) in the future. Consequently, the 2G and 3G spectrum allocations in Hong Kong will decrease whereas the 4G spectrum allocation will increase (as shown in Exhibit 5.4). These pre-existing refarming allocations are included in the analysis for both the base case and alternative scenarios (when there is no mitigation). The spectrum refarming assumed as a mitigation strategy modifies and is **in addition** to the operators' pre-existing spectrum refarming plans (which are incorporated into the base case).

[✂……………………………………………………………………………………….

	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
China Mobile								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
CSL								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
HKT								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
Hutchison								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
SmarTone								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..

Exhibit 5.2: *850–900MHz band refarming scheme [Source: Office of the Communications Authority and operators]*

	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
China Mobile								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
CSL								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
HKT								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
Hutchison								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..
SmarTone								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G	…..	…..	…..	…..	…..	…..	…..	…..

Exhibit 5.3: *1800MHz band refarming scheme [Source: Office of the Communications Authority and operators]*

Year	*2G*	*3G*	*4G (FD-LTE & TD-LTE)*
2013	…..	…..	………………………………………………………… ………………………………………………………… …………………
2016	…..	…..	………………………………………………………… ………………………………………………………… ………………………………………………………… …………………
2018	…..	…..	………………………………………………………… …………………
………			

Exhibit 5.4: *2G, 3G and 4G spectrum allocations in Hong Kong [Source: Office of the Communications Authority and operators]*

………………………………………………………………………………………………….]CI

Some operators are planning to refarm a part of the 3G spectrum in the 850-900MHz band to 4G, and therefore their capacity to serve a given 3G demand will reduce and may lead to congestion (even in the base case) in the 3G networks. We believe that operators want to ensure continued services levels and should migrate their 3G customers to their 4G networks in line with spectrum refarming. As noted above, if operators accelerated this migration of 3G customers to 4G, then the impact on the 3G hotspot network could be reduced.

When the spectrum is re-assigned in the 1.9–2.2GHz band, there is a possibility that some incumbent operators may lose their 2×5MHz re-auctioned 3G spectrum and hence their capacity to serve the given 3G demand will decrease. However, in the light of the steady decrease in 2G demand, Network Strategies suggests that additional 2G spectrum may be refarmed to 4G (Exhibit 5.5) as well as modification of pre-existing refarming plans (Exhibit 5.6) to mitigate the effects of possible spectrum loss in the 1.9–2.2GHz band. Note that refarming 2G spectrum to 4G only alleviates the throughput loss on the 3G network if demand is also migrated from 3G to 4G. The demand used in this analysis is unchanged across the scenarios to ensure that it is consistent with the data provided by the operators therefore only the modification of pre-existing refarming plans (Exhibit 5.6) affects the results on the 3G network.

The 2G to 3G refarming scheme assumed as a mitigation strategy in this study by the individual operators is outlined in Exhibit 5.6. Note that this mitigation strategy is a modification to the refarming schemes outlined in Exhibit 5.2, which include some 3G to 4G refarming.

[✂…………………………………………………………………………………………

Operator	*850–900MHz*	*1800MHz*
…..	…..	…..
…..	…..	…..
…..	…..	…..
…..	…..	…..

Exhibit 5.5: *Additional spectrum for refarming in 2016 [Source: Network Strategies Limited]*

Operator	*850–900MHz*	*1800MHz*
…..		
Current plan	…..	…..
Modified plan	…..	…..
…..		
Current plan	…..	…..
Modified plan	…..	…..
…..		
Current plan	…..	…..
Modified plan	…..	…..
…..		
Current plan	…..	…..
Modified plan	…..	…..

***Exhibit 5.6**:* *Current operator refarming plans of 2014 and modifications applied for the mitigation strategies [Source: Network Strategies Limited]*

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5.3 Improve spectrum efficiency

The third strategy to improve capacity is to increase spectral efficiency, which in turn depends on availability of more advanced wireless technologies.[41] This includes upgrading the deployed technologies, such as HSPA+ to HSPA+ Advanced and LTE to LTE Advanced as well as implementing MIMO techniques.[42] However, deployment of the advanced technologies and the development of devices to support them are still in progress.

41 Qualcomm (2012), *The 1000x Mobile Data Challenge,* available at http://www.qualcomm.com/media/documents/files/wireless-networks-1000x-mobile-data-challenge.pdf.

42 Qualcomm (2012), *Rising to Meet the 1000x Mobile Data Challenge,* available at http://www.qualcomm.com/media/documents/files/wireless-networks-rising-to-meet-the-1000x-mobile-data-challenge.pdf.

Exhibit 5.7 shows the main features[43] and the expected dates of initial commercial deployments of some 3G and 4G technologies defined under Releases 8-11.[44]

Note that we do not consider an upgrade pathway from HSPA+ to LTE. HSPA+ is a 3G technology while LTE is 4G, and therefore a replacement of HSPA+ by LTE requires 3G spectrum to be refarmed to 4G. We consider that this strategy, over and above the operators' pre-existing refarming plans, would be unlikely within the model timeframe as it would increase 3G congestion given that there will still be a significant subscriber base with 3G handsets (Exhibit 4.3).

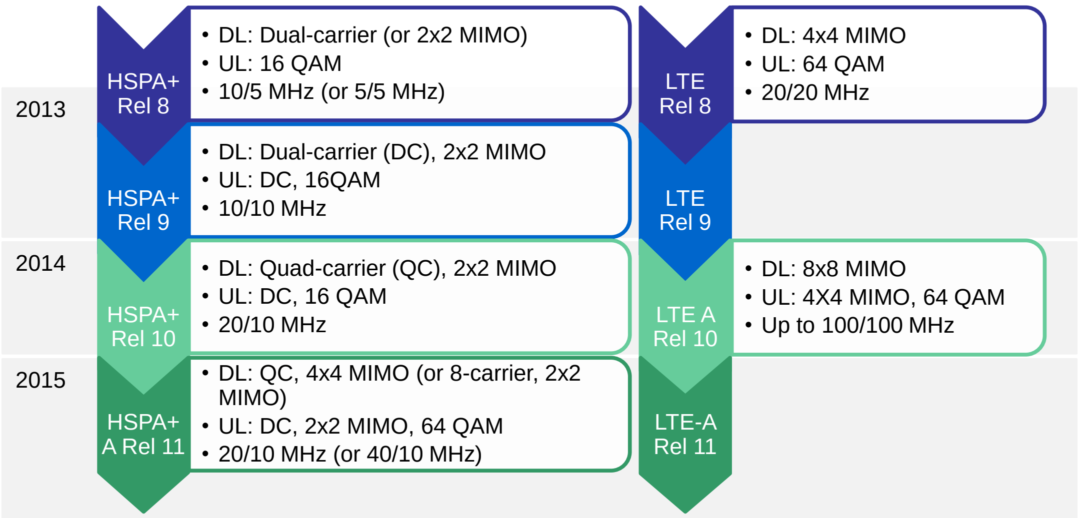

Exhibit 5.7: *Evolution of 3G and 4G technologies [Source: Qualcomm[45] and Network Strategies]*

These advanced technologies are spectrally more efficient as they implement enhanced MIMO techniques and support wider bandwidth.[46] They also enable different spectrum

43 Nokia Siemens Networks (2012), *Long Term HSPA Evolution meets ITU IMT-Advanced requirements.*

44 4G Americas (2012), *Mobile Broadband Acceleration in the Americas,* available at http://www.4gamericas.org/UserFiles/file/Presentations/2013/May%2014%20Mobile%20Broadband%20Acceleration%20in%20the%20Americas%20Chris%20Pearson.pdf.

45 Qualcomm (2013), *Technology Roadmap with Spectrum Update.*

holdings across multiple bands – including both paired and unpaired – to be combined in order to improve capacity. [47]

Exhibit 5.8 shows the maximum speed (in Mbit/s) and peak spectral efficiency (in bit/s/Hz) of some 3G and 4G technologies for downlink.[48] The peak efficiency is achieved under ideal conditions whereas the average spectral efficiency quantifies the technology performance and user experience more likely to be experienced in real-life networks.[49] Hence, average spectral efficiency values (given in Section 6.2) have been used in this study.

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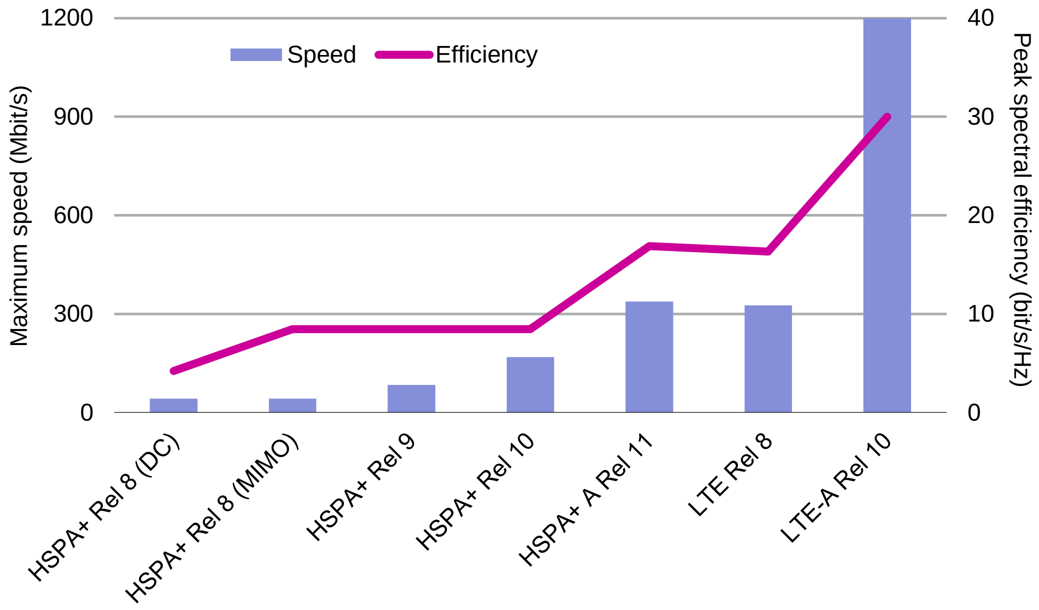
46 Rysavy Research/4G Americas (2012), *Mobile Broadband Explosion,* available at http://www.4gamericas.org/documents/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%2020121.pdf

47 3GPP (2012), *LTE-Advanced,* available at http://www.3gpp.org/lte-advanced.

48 Qualcomm (2013), *HSPA+ R7, R8, R9 and R10,* available at http://www.qualcomm.com/media/documents/files/hspa-evolution-enhanced-mobile-broadband-for-all.pdf and Rysavy Research/4G Americas (2012), *Mobile Broadband Explosion,* available at http://www.4gamericas.org/documents/PPT%20-%20Rysavy%20Mobile%20Broadband%20Explosion%202012.pdf.

49 Rysavy Research/3G Americas (2008), *EDGE, HSPA, LTE – Broadband Innovation,* available at http://www.4gamericas.org/documents/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%2020121.pdf and 3GPP (2011), *3GPP Radio Access Networks LTE-Advanced Status,* available at http://www.3gpp.org/ftp/information/presentations/presentations_2011/2011_09_LTE_Asia/2011_LTEAsia_3GPP%20RAN.pdf.



Note: LTE-A Rel 10 values are for 40/40MHz spectrum and higher speeds can be achieved with carrier aggregation (up to 100/100MHz spectrum)

Exhibit 5.8: *Maximum speed and peak spectral efficiency for downlink [Source: Network Strategies]*

Hong Kong is a mature mobile market with HSPA+ Rel 8 implemented (with a maximum download speed of 42Mbit/s) by most operators in the 1.9–2.2GHz spectrum band. Any further technology upgrades in 3G (HSPA+) would require implementation of MIMO antennas and thus additional investment in the network. Any efficiency gains also depend on availability of compatible mobile handsets and customer adoption of those handsets. Although new handsets are expected to support MIMO, a significant proportion is expected to contribute to 4G (LTE) traffic rather than 3G. Consequently, Hong Kong operators have prioritised investment in LTE over HSPA+ technology. Hence, for the purpose of this study we have assumed that there will be no increase in 3G spectral efficiency.

Commercial deployments of LTE Advanced are planned in some countries (including South Korea and the United States) this year.[50] In addition, a number of compatible devices

50 Engadget (2013), *SK Telecom launches the world's first LTE-Advanced network, and the Galaxy S4 LTE-A*, available at http://www.engadget.com/2013/06/25/sk-telecom-lte-advanced-galaxy-s-4/.

are expected to launch this year.[51] As Hong Kong has a sophisticated mobile market, it is expected that operators will begin upgrading their LTE networks to LTE Advanced in 2015. However, 4G customers may not have LTE Advanced compatible handsets initially and thus the transition (to LTE Advanced) is assumed to happen gradually over the modelling period.

Refarming of 3G spectrum for the use of LTE (4G) technologies cannot be employed in this study as a mitigation strategy to relieve congestion on the 3G network. LTE offers the potential for increased spectrum efficiency, as the standard is still being developed, whereas this is not the case for 3G technology. For this analysis operators have provided data including the expected migration of subscribers from 3G to 4G handsets. Therefore the increasing spectrum efficiency in the 4G standard cannot be used as a mitigation strategy for congestion in the 3G networks without also modifying the demand inputs. In this study we have used the demand projections by technology obtained from operators and therefore cannot make justifiable adjustments as to the allocation of incumbent operators' traffic across those technologies (i.e. the operators' 4G networks is unable to carry 3G traffic). Therefore, the increase in spectrum efficiency available in the LTE standard does not relieve congestion in the 3G network for the given demand profile and, for the purposes of this analysis, increasing spectrum efficiency is not considered as a mitigation strategy as the only potential increase in spectrum efficiency is in the 4G standards over the modelling period.

5.4 Increase number of cell sites

Macrocells are deployed to provide large cellular coverage (and low capacity) in areas with low traffic density whereas microcells are deployed in urban areas to provide moderate coverage (and capacity).[52] In contrast, picocells and femtocells are deployed to serve small areas with high density traffic (hotspots), thus providing low coverage and high capacity.

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51 Android Authority (2013), *Samsung officially announces the Samsung Galaxy S4 LTE-A,* available at http://www.androidauthority.com/samsung-galaxy-s4-lte-a-official-235482/, and ZDNet (2013), *Apple, SK Telecom to unveil LTE-A iPhone 5S,* available at http://www.zdnet.com/apple-sk-telecom-to-unveil-lte-a-iphone-5s-7000017565/.

52 Rysavy Research (2011), *Efficient Use of Spectrum,* available at http://www.rysavy.com/Articles/2011_05_Rysavy_Efficient_Use_Spectrum.pdf.

Operators serve customers with Heterogeneous Networks (HetNets) having a combination of large and small cells operating on multiple technologies (2G, 3G and 4G).[53] HetNets are deployed to manage the coverage and capacity requirements and use the available spectrum efficiently.

The capacity of a network may be increased by the deployment of additional smaller cell sites that reuse the existing frequency bands more intensively.[54] This commonly suggests the deployment of femtocells (which focus on serving the indoor traffic) in addition to picocells (to complement the existing network in hotspots).[55]

Currently, Hong Kong has a dense layout of cellular network (especially in hotspots) and additional cell sites (required to serve the growing traffic) are already planned by the operators and included in the impact model under the base case scenario. It is therefore assumed in the impact model that operators will not deploy sites in addition to those already planned.

5.5 Offload to WiFi networks

The use of technologies such as WiFi and femtocells for offloading traffic is a strategy used to relieve network congestion[56], as well as to enable operators to reduce or defer investment. WiFi, in particular, has been extensively deployed by a number of operators around the world for mobile data offloading. There are still concerns, however, about its capacity to deliver the same user experience as the traditional mobile network:

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53 *Ibid.*

54 Qualcomm (2012), *The 1000x Mobile Data Challenge,* available at http://www.qualcomm.com/media/documents/files/wireless-networks-1000x-mobile-data-challenge.pdf.

55 Qualcomm (2012), *Rising to Meet the 1000x Mobile Data Challenge,* available at http://www.qualcomm.com/media/documents/files/wireless-networks-rising-to-meet-the-1000x-mobile-data-challenge.pdf.

56 Network Strategies (2012), *Mobile data offloading: dealing with the mobile data traffic boom*, http://www.strategies.nzl.com/wpapers/2012013.htm

> With WiFi, the operators' concern is whether this technology is capable of serving as an alternative to offload mobile data traffic offering an architecture which is as secure, controllable and reliable as their 3G networks. Taking into consideration that WiFi is relatively variable in terms of quality of service, enabling multiple services with specified quality levels may be a difficult task.[57]

Various analysts claim that operators will increase the amount of mobile data traffic offloaded to WiFi and femtocells. According to Cisco, ABI Research and Juniper Research, 30–60% of total data traffic will be offloaded from mobile networks (3G and 4G) by 2015.[58]

These predictions should however be treated with caution when considering the Hong Kong market, due to key differences between the Hong Kong environment and those in other markets.

WiFi's use of unlicensed and unmanaged spectrum makes the service susceptible to interference caused by other authorised telecommunications equipment. In a densely populated area as Hong Kong, interference is a major constraint when deploying WiFi hotspots to increase coverage, especially in areas of high traffic density. This will reduce the ability of operators to boost the amount of mobile data offloaded.

The five MNOs in Hong Kong currently use **[✂**…….[59] of licensed spectrum to provide their mobile services. Currently Hong Kong has 83.5MHz in the 2.4GHz band and 580MHz in the 5GHz band available for WiFi services[60]. This seemingly more than doubles the amount of spectrum available for mobile data services. However, the WiFi

57 Network Strategies Limited (2012), *Mobile data offloading: dealing with the mobile data traffic boom*, available at http://www.strategies.nzl.com/wpapers/2012013.htm

58 Wireless Broadband Alliance (2012), *Next Generation Hotspot Whitepaper: Maintaining the Profitability of Mobile Data Services*, available at http://www.wballiance.com/resource-center/white-papers/

59 **[✂**……… ……… ……… ………………………………………………………………………………**]CI**

60 In addition to WiFi services, this spectrum may be used for Industrial, Scientific and Medical (ISM) Equipment, Amateur-satellite and Radiolocation.

spectrum is also used by unlicensed providers, such as hotels and cafés, as well as thousands of home users. This means that it is impossible to calculate the actual amount of spectrum available for WiFi offload for MNOs.

According to information provided by Hong Kong MNOs, we understand that they aim to provide consistent service levels with their customers, **[✂**…………………..…………………………………………………………………………………………[61]**]CI**. WiFi offload is not able to deliver any level of service guarantee and therefore the operators are unable to rely on it as a resource for their mobile networks.

Other regulators have noted the problems associated with the use of unlicensed or 'public park' spectrum:

> Some niche operators deploy services in public park spectrum, but it is not favoured by comprehensive service carriers and larger-scale ISPs, particularly those with government infrastructure funding. This is because they cannot guarantee and manage QoS due to the risk of interference, especially in high spectrum use areas. Another major problem with public park spectrum is 'the tragedy of the commons' whereby too much unfettered use can make the band less than ideal for some services.[62]

A survey[63] conducted by the Wireless Broadband Alliance (WBA) in 2012 found that the top three barriers to adoption and use of public WiFi are authentication issues, lack of a common roaming standard and issues associated with 3G/WiFi interworking.

According to a 2013 survey conducted by Ericsson[64], network performance is the principal driver of customer loyalty to network operators. Operators would therefore be reluctant to deploy solutions that would threaten customers' perception of performance. Ericsson also

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61 **[✂**……**]CI**

62 Australian Communications and Media Authority (2006) *Strategies for wireless access services*, Spectrum Planning Discussion Paper SPP 1/06, February 2006.

63 Wireless Broadband Alliance (2012) *WBA Wi-Fi Industry Report: global trends in public Wi-Fi*, November 2012.

64 Ericsson (2013) *Ericsson mobile report: on the pulse of the networked society*, June 2013.

notes[65] a number of issues inherent in device-driven WiFi that can result in degradation of service:

- the WiFi-enabled device attaches to WiFi when in range, even if the connection does not deliver a good user experience or if only temporary access is available (such as for users in motion)
- the WiFi-enabled device attaches to a congested WiFi network, even if the mobile (3G or 4G) network is lightly loaded
- WiFi in many cases has a lower bandwidth backhaul than that used for mobile, in order to minimise costs, which can deliver a poorer user experience.

While technical solutions and standards are being developed to address a number of these issues, we believe that WiFi offloading is unlikely to be a feasible mitigation strategy for operators in Hong Kong.

With the population concentrated in very high density urban areas, and with one of the world's highest mobile penetration rates, it will be a significant challenge for operators in Hong Kong to reach the same levels of data offload being claimed in other markets, or to achieve major improvements in relation to the current conditions without any deterioration in the quality of service. [✂……………………………………………………………
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65 Ericsson (2013) *WiFi in heterogeneous networks: an integrated approach to delivering the best user experience*, June 2013.

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..... ………………………………………………………………………… ………………………………………………………………………… ………………………………..**]CI**

Further comments were previously made by CSL as part of the submissions to OFCA's first consultation paper:

> Wi-Fi will help offload mobile data traffic but there are major issues that need to be overcome. Under the current regulatory regime, the frequency bands allowed for Wi-Fi are used on a shared basis in an uncoordinated manner with no limitation on the number of service providers. While Wi-Fi equipment should not cause harmful interference, it is not protected from harmful interference caused by other authorised telecommunications equipment.
>
> Specifically, Wi-Fi needs to be coordinated amongst all the operators since all 3G mobile networks in Hong Kong are busy in the same places, e.g. the MTR. Wi-Fi as a technology also has issues with large amounts of data traffic. For example, a good 20 Wi-Fi access points are visible outside the Sogo department store in Causeway Bay. Should these access points become very busy, they will essentially interfere with one another and severely decrease the performance of all Wi-Fi points in the area.

In the long term, WiFi offload is an unsustainable method of providing reliable mobile broadband services to end users due to its inherent 'best efforts' quality of service and the interference that is a characteristic of the high density Hong Kong environment.

It is Network Strategies opinion that the scale of the effect due to WiFi offload reported in the press for overseas markets has been exaggerated and is not relevant for this study. It is possible that the reports of WiFi offload are in fact confused with WiFi services being provided by private operators and this is being compared to the demand being carried on mobile networks. It is impossible to judge the veracity of these claims without research into each one individually. Claims are frequently vague and misleadingly quoted in media reports, which makes verification quite difficult. In addition, WiFi is incapable of providing a guaranteed quality of service, whereas this study is concerned with maintaining the level of service to the Hong Kong market under different spectrum re-assignment scenarios.

The Hong Kong MNOs are deploying WiFi in congested hotspots, such as the MTR. We are unable to comment on the business rationale of these decisions, however we still believe that WiFi data cannot be included as mobile services on MNO networks in this study. **[✂**…………………………………………………………………………………… ……………………………….**]CI** It is impossible to quantify the data offloaded to WiFi and these services do not provide a quality of service comparable to public mobile network services. For these reasons we have excluded WiFi from our analysis.

5.6 Conclusions

The five mitigation strategies and their applicability to this study are summarised in Exhibit 5.9. These opinions represent Network Strategies' views and are current as at the time of writing this report. We note that as technological development is ongoing these conclusions may become superseded towards the end of the modelling period. Mitigation strategies should be seen in the context of individual networks and as business decisions of individual operators. In conclusion, we believe that further spectrum refarming is the most feasible strategy to mitigate any potential service degradation.

Mitigation strategy	*Applicability*	*Comment*
Acquire additional spectrum	✗	No new spectrum bands will be released in Hong Kong during the modelling period.
Refarm existing spectrum	✓	2G deployed on 850/900MHz and 1800MHz bands may be refarmed to either 3G or 4G services.
Improve spectrum efficiency	Limited	No increase in 3G spectral efficiency due to limited availability of compatible MIMO 3G handsets. Increase in spectral efficiency in 4G does not relieve 3G network congestion for a given demand profile.
Increase number of cell sites	Limited	New cell sites that have been planned by operators during the modelling period have been included in the base case analysis. Hong Kong MNOs are emphatic that no new sites in addition to those already planned are possible.
Offload to WiFi networks	Limited	[✂…………………………………………………… ………………………………………………………… ………………………...**]CI** No increase to this offload was included as part of our study as it is our opinion that it cannot provide a similar level of service under varying spectrum re-assignment scenarios.

***Exhibit 5.9**:* *Summary of mitigation strategies [Source: Network Strategies]*

6 Impact model

6.1 Methodology

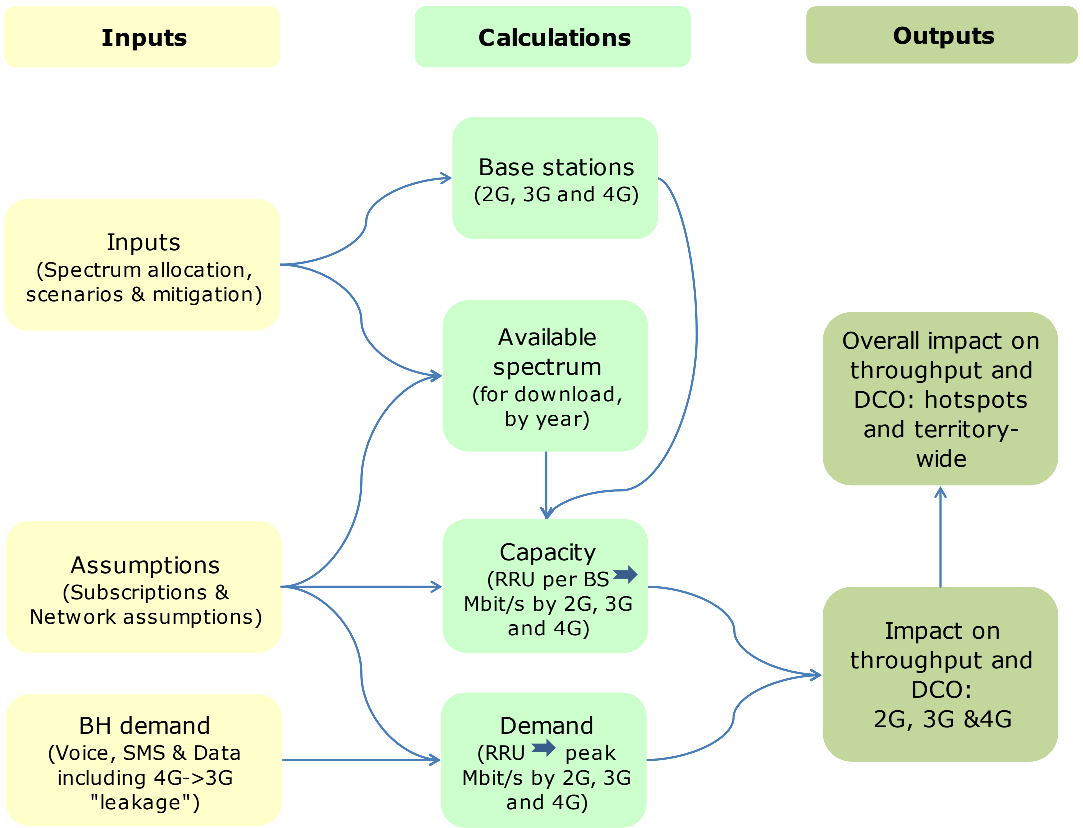
To assess the effect on quality of service for mobile services in the entire Hong Kong market, a bottom-up approach is used within the impact model. It should be noted that this is a very different approach to that used by OFCA in the second consultation paper[66] and as such there is no relationship between OFCA's previous estimates and those obtained from our model.

This model consists of two parts – demand and supply (Exhibit 6.1).

The demand component of the model uses the forecasts (discussed in Section 4) for mobile traffic (including circuit switched voice, IP voice, messaging and data services) in two regions, namely hotspots and territory-wide. The model covers a six-year modelling period, 2013–2018. This timeframe encompasses the period leading up to the spectrum reassignment as well as the transitional period after the reassignment. Network Strategies believes that a two-year post-reassignment period is ample for an incumbent mobile operator to re-configure its network in order to re-establish the quality of service levels during the transition. This takes into account the fact that the re-auction of the 2×20MHz spectrum will be conducted by October 2014 and an operator will have at least two years' notice to plan for the service provision with the assigned spectrum as from October 2016.

66 Commerce and Economic Development Bureau and the Communications Authority (2012), *Second Consultation Paper on Arrangements for the Frequency Spectrum in the 1.9 – 2.2GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services,* available at http://www.coms-auth.hk/filemanager/en/share/cp20121228.pdf.

The supply component calculates total network capacity, which depends on three factors – spectrum bandwidth, spectral efficiency and number of base stations both in hotspots and territory-wide. The spectrum available to each MNO will depend on the spectrum re-assignment scenarios (discussed in Section 3). The spectrum and spectral efficiency is combined to calculate the spectral capacity for each MNO (Exhibit 6.1). The number of cell sites in hotspots and territory-wide, provided by MNOs, is used to calculate the network capacity (for every MNO). The total available capacity is a combination of the spectral and network capacity.



DCO: Design Capacity Overage

Exhibit 6.1: *Model map for impact modelling [Source: Network Strategies]*

The demand and supply components are combined to calculate the impact on two Quality of Service (QoS) measures: busy hour network throughput (in Mbit/s) and busy hour network Design Capacity Overage or DCO (expressed as a percentage). The final model output includes the percentage change of these two measures (compared to the base case) for hotspots and territory-wide.

Two levels of analysis are undertaken. The first is done by varying the spectrum bandwidths while assuming all other input variables remain constant for all the scenarios. The second considers the effects of other variables in improving QoS metrics as part of mitigation strategies.

Network Strategies has used the following information from the operators as inputs (current and projected values) to the impact model:

- total customers split by technology (2G/3G/4G)
- total and busy hour data traffic (including roaming) split by technology (2G/3G/4G) and geo-type (hotspot or urban)
- spectrum holdings and spectral efficiencies split by technology (2G/3G/4G) and geo-type (hotspot or urban)
- number and distribution of base stations in different spectrum bands split by technology (2G/3G/4G) and geo-type (hotspot or urban).

The model includes confidential data and calculations for all existing MNOs and is therefore unsuitable to be distributed publicly due to the confidential nature of the operator data. Some gaps and inconsistencies are noted in the data supplied by the MNOs. It has therefore been necessary for Network Strategies to apply assumptions in some instances in order for the analysis to be performed.

6.2 Assumptions

In addition to the data supplied by the MNOs, we have made a number of assumptions regarding the demand and supply components of the model over the modelling period. These assumptions are based on publicly available information and our own internal databases. The assumptions were provided to and agreed by the MNOs and are outlined below. Any assumptions made by Network Strategies subsequent to the operator consultation are also noted below.

Demand side assumptions

The two main elements of demand are subscriptions and traffic, with the traffic being comprised of voice, SMS and data.

- **Subscriptions:** While subscriptions are not used directly within the impact model, they were used to derive some assumptions and to cross-check the model behaviour. The subscription projections were supplied by the operators, who also disaggregated these into 2G, 3G and 4G. Thus the operators' own projections on technology migration were used, with some exceptions as noted in Section 4.2.

- **Voice traffic:** Voice services are included within the impact model. The majority of the operators did not provide either current or projected voice traffic. Voice traffic projections within the model are therefore based on our assumptions (see Section 4.2 for more details).

- **SMS traffic:** SMS traffic is also included in the model; however most operators provided no information on SMS. As in the case of voice, the SMS traffic projections are based on our assumptions (see Section 4.2).

- **Data traffic:** In general, the projections for data traffic are based on those provided by the operators (described in more detail in Section 4.2). Each operator also disaggregated its projected data traffic into 2G, 3G and 4G. We have therefore used the operators' own projections on migration of data traffic to 4G technology, with some exceptions as noted in Section 4.2.

The impact model also uses a number of other demand-side assumptions:

- **Hotspots:** Operator data traffic (current and projected) was provided to Network Strategies disaggregated into that carried on hotspot and urban sites. The hotspot sites were defined as those sites that carry the most network traffic. Hotspots as a proportion of total sites varies by operator (either 15% or 20% of the base stations) but in both cases these sites carry 40% of network traffic.

- **4G traffic carried by 3G networks:** The 4G demand (provided by the operators) is adjusted to account for the overflow of 4G traffic onto 3G networks whilst 4G networks are being deployed. This will particularly affect voice traffic as Voice over LTE (VoLTE) can only be implemented based on the availability of compatible devices and the upgrade of 4G network to LTE-A. The proportion of 4G traffic assumed to be on the 3G network over the modelling period is shown in Exhibit 6.2. This assumption is made by Network Strategies.

	2013	*2014*	*2015*	*2016*	*2017*	*2018*
Voice	100%	100%	75%	50%	25%	15%
Data & SMS	20%	15%	5%	0%	0%	0%

Exhibit 6.2: *Assumed proportion of 4G traffic carried by 3G network [Source: Network Strategies]*

- **Market share:** It is also assumed that market shares of MNOs (i.e. percentage of total market subscriptions) do not change between the base case and the scenario being examined, namely that customers do not churn to operator(s) with increased 3G spectrum holdings. We expect that MNOs would employ various strategies to maximise customer retention, including the expansion of network capacity by accelerating the 4G network rollout as well as actively encouraging customers to take up 4G services (for example through price promotions and 4G handset subsidies).

Supply side assumptions

The network assumptions outlined in Exhibit 6.3 comprise the standard engineering assumptions applied in the impact model.

Parameter	*Value*	*Source*
IP overhead	12%	Industry accepted assumption
Blocking probability	**[✂..]CI**	Operator input
Download proportion	**[✂..]CI**	Operator input
2G call data rate (kbit/s)	14	Industry accepted assumption
2G data (GPRS) call rate (kbit/s)	9	Industry accepted assumption
2G channels per TRX	8	Industry accepted assumption
2G channel width (kHz)	**[✂..]CI**	Operator input
3G call data rate (kbit/s)	12.2	Industry accepted assumption
3G channels per RRU	32	Industry accepted assumption
3G channel width (MHz)	**[✂..]CI**	Operator input
3G allowance for soft handover	70%	Industry accepted assumption
4G call data rate (kbit/s)	64	Industry accepted assumption
4G channel width (MHz)	**[✂..]CI**	Operator input
4G allowance for soft handover	70%	Industry accepted assumption
Network design utilisation	75%	Industry accepted assumption (used to calculate DCO)

Exhibit 6.3: *Network assumptions used in the model [Source: Network Strategies and Hong Kong MNOs]*

The limiting factor on capacity is assumed to be download throughput. There is further discussion on this topic in Section 6.3 below.

Base stations

All operators provided information on current base station numbers disaggregated into those that were defined as “hotspot” sites (defined as the sites carrying the most traffic) and “urban” sites (the remaining sites). Some operators also provided projections of base stations for the entire modelling period, which we used within the impact model. However for operators that did not provide this information, we derived base station projections that are consistent with the projections supplied by the other incumbent operators.

The average radio units per base station per MHz spectrum were calculated using operator data. MNOs provided Network Strategies with the average number of radio units per base station. This data was disaggregated into 2G, 3G and 4G as well as hotspot and territory-wide. The total spectrum holdings available for each operator were used to calculate the average radio unit figures shown in Exhibit 6.4. These figures were used to calculate the network capacity and are used as an assumption in the impact model.

[✂...……………………………………………………………………………………

Type of base station	*Value*
2G hotspot	…..
3G hotspot	…..
4G hotspot	…..
2G site	…..
3G site	…..
4G site	…..

Exhibit 6.4: *Radio units per MHz [Source: Network Strategies]*

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It is expected that no additional spectrum will be available to MNOs over the modelling period as per our discussion in Section 5.1 of this report.

The assumed spectral efficiency of the mobile technologies was based on Network Strategies research and operator input. The absolute value for 2G spectral efficiency is assumed to be [✂......…......**]CI** currently. The relative values of the three technologies over the modelling period are shown in Exhibit 6.5. The model assumes that both 2G and 3G technology is stable and no further improvements in spectral efficiency occur during the modelling period. Theoretical research indicates that both “4×4 MIMO” and “8×8 MIMO” can increase capacity significantly. However, currently there are no mobile devices and base stations supporting these technologies. All Hong Kong mobile operators have informed us that these technologies are very difficult to implement in practice. Therefore, we have not assumed any technological upgrades for the existing 2G and 3G networks (and hence no MIMO assumptions have been made for these networks). For 4G networks, we have not assumed MIMO technologies until 2015 (though commercial deployments are planned in some countries this year). In addition, we envisage that it is unlikely that all the 4G customers will have compatible handsets in 2015 and hence, we have assumed that the transition will happen gradually over the modelling period. The spectral capacity assumptions in the model are in accordance with feedback provided by

MNOs. The model assumes current 4G technology is LTE release 8 and that release 10 will be deployed in 2015. The change in spectral efficiency for 4G technology over the modelling period reflects both the network and handset deployment.

Technology	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
2G	×1.00	×1.00	×1.00	×1.00	×1.00	×1.00
3G	×1.94	×1.94	×1.94	×1.94	×1.94	×1.94
4G	×3.77	×4.51	×5.23	×5.97	×6.40	×6.80

Exhibit 6.5: *Relative spectral efficiency of 2G, 3G and 4G technologies over the modelling period [Source: Network Strategies and Hong Kong MNOs]*

These figures were largely informed by operators' input and are based on actual network measurements, in the case of 2G and 3G, and theoretical calculations for 4G. **[**✂…
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6.3 Quality of service calculations

This study considers the effect on the whole Hong Kong market. As such it is not appropriate for us to consider the individual impacts on a site-by-site basis. Operators' networks are modelled as building blocks within the impact model so that the effects on individual networks are contained within the market wide results and analysed in general terms that do not allow individual operators to be identified within this report.

The output goal of the model is to calculate changes in throughput (in Mbit/s) and DCO (expressed as a percentage) both for hotspot areas and territory-wide. The throughput calculated by the model is total downloaded throughput in the busy hour. DCO is calculated as the percentage of offered traffic (demand) that is unable to be met by the network design capacity, which is assumed to be 75% of the total network capacity in this model, in the busy hour. Busy hour is the network parameter used to dimension mobile networks.

These metrics were primarily used as they are relatively easy to model and provide a reasonable high level assessment for quality of service and customer experience across the whole Hong Kong market. They are not the metrics used by network operators to dimension and operate their networks, nor can they provide a service impact assessment on a per-customer basis which is not the objective of this study. The quality of service metrics used are defined in the model as follows:

- throughput = minimum of demand and capacity
- DCO = maximum of zero and (demand – utilisation × capacity) / demand (where utilisation is the network design utilisation with a value of 75% as outlined in Exhibit 6.3).

The throughput gives an indication of the change in total network capacity across the Hong Kong market under the different scenarios. If demand is greater than capacity then the throughput is equal to capacity as the network is unable to transport more than its capacity. If capacity is greater than demand then throughput is equal to demand as all the demand is being met.

The DCO metric gives an indication of how much excess demand is unable to be met by the network design capacity, namely 75% of the total network capacity. The DCO is zero if demand is less than 75% of the total network capacity. It is consistent with standard network engineering assumptions that the network shows positive DCO if demand is greater than 75% of total capacity. If there is no capacity the DCO is 100%. Therefore DCO is always between 0% and 100%.

The network utilisation figure of 75% is used in the DCO calculations to allow for the statistical nature of telecommunications traffic. Both the demand and capacity results calculated in the impact model are based on busy hour calculations. Demand is calculated from instantaneous traffic averaged over the entire busy hour and therefore does not reflect the reality of traffic on telecommunications networks – which may be at levels above 75% utilisation at some instances and at levels below 75% at other instances during the busy hour – or the user experience. **[**✂……………………………………………………...…….

…………………………………………………………………………………………………… ……………………..….**]CI** In an environment such as Hong Kong, we consider that this type of behaviour is not unexpected. To reflect correctly the impact to customers on the live networks, a network utilisation figure is necessary to allow for these considerations.

These metrics are not those used by network operators to design their networks. The main objective of this study is to assess the effect of different spectrum-reassignment scenarios on the whole of market. In making this assessment both technical and demand data from individual operators have been used, so that the whole of market effect captures the combined impact on each individual operator. However it was beyond the scope of the study to undertake a detailed network radio-planning design exercise for each operator. The impact on individual operators under each scenario is included in the model, which has been provided to OFCA, however not included in this report due to the confidential nature of the data provided to Network Strategies by the individual network operators. The maximum and minimum individual operator values have been included in the results section of this report. In this manner, an operator impact assessment may be made without exposing the identity of the individual networks.

It is our professional opinion that for a **whole of market effect**, throughput and DCO are adequate metrics and will achieve the study objective. Furthermore this is consistent with what was claimed by the operators' consultant, Plum Consulting, as part of its response to the Second Consultation Paper when referring to the assessment on customer service degradation conducted by OFCA which used download speed as a metric:

> Annex 2 focuses on download speed whereas the key factor for meeting demand is the capacity or data throughput of the network. A high capacity network is achieved by a combination of the amount of spectrum available and the reuse of spectrum (determined by network layout).[67]

[67] Communications Authority website, Completed Consultations & Submissions, available at http://www.coms-auth.hk/en/policies_regulations/consultations/completed/index_id_175.html.

CSL's submission on the Second Consultation Paper also highlighted the importance of throughput as a metric[68]:

> As noted in the Second Plum Report, the CA makes the mistake in Annex 2 of focussing on download speed. The key factor, however, for meeting demand is the capacity or data throughput of the network.

Individual operators' networks are modelled at a high level as an input to these calculations which ensures that the model represents as closely as possible the actual situation in Hong Kong rather than a purely theoretical model. The operators provided us with data regarding the busy hour total throughput on their networks, but were not able to provide the information regarding the number of simultaneous users on the network during that busy hour. Any assumption made by Network Strategies would have no justifiable basis as no information on this topic is publicly available. Therefore, in the absence of this information from the operators themselves, we are unable to calculate impact on individual customer download speed. This includes the inability to calculate metrics such as "percentage of cells not being able to offer a minimum speed of **[✂………..]CI** of the time." Further, even with this information, this metric would be beyond the scope of this study as it would require detailed analysis of operator networks on a site by site level of disaggregation.

Hong Kong MNOs have been very generous in their time and information for the model development and this analysis would not have been possible without their input. Network Strategies was presented with suggestions of various metrics, such as power, code, uplink noise, voice and signalling limitations, that the operators use to monitor and dimension their own networks as more appropriate inputs for this study. These metrics all require per base station calculations, which involves a level of detail and complexity unnecessary for the analysis required for this report. The impact model does not calculate per base station (or site) impacts nor individual subscriber service level impacts as such a level of detail is neither possible nor necessary for the objective of this study.

68 CSL (2013), *Arrangements for the Frequency Spectrum in the 1.9 - 2.2 GHz Band upon Expiry of the Existing Frequency Assignments for 3G Mobile Services – Second Consultation Paper Submission by CSL Limited to the Office of the Communications Authority,* 11 April 2013. See page 15.

The demand for voice services is included within the analysis of this study. Voice demand is aggregated within the total demand being carried on the individual networks, however is unable to be disaggregated in the final analysis to provide a metric such as percentage dropped calls. Voice calls on 3G and 4G networks are carried over the same physical channels as data and so the effect on dropped calls is largely a matter for individual network parameters, such as handover parameters and the priority assigned to voice calls.

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We agree that this analysis provides an aggregate view and therefore many of the individual subscribers will have experiences worse than this aggregate and many will have better experiences than the average. It is simply beyond the scope of this study to conduct analysis at a level as detailed as that undertaken by the operators in the day-to-day running of their network operations.

In calculating throughput, the reduced capacity of any network operator with a reduced spectrum assignment is also calculated. There is no reduced coverage as the model assumes that all 3G incumbent operators choose to exercise their right of first refusal and retain two-thirds of their current spectrum in the band. Thus we only consider the likely re-assignment outcomes of auctioning the remaining one-third.

6.4 Responses to operator feedback

The MNOs were provided with opportunities to comment on the draft impact model and its preliminary results. This feedback was subsequently taken into account when finalising the model. A summary of the feedback and our responses is provided in Annex B.

7 Analysis of model results

The impact model calculates the busy hour throughput (in Mbit/s) for both hotspot areas and territory-wide for the base case, the four likely scenarios (discussed in Section 3) and the extreme scenario (scenario 3).

The model is particularly sensitive to demand forecasts, base station number projections and network assumptions and as such these results are a reflection of the input data provided to Network Strategies from the Hong Kong MNOs.

All calculations in the model are undertaken separately by operator, technology (2G, 3G and 4G) and by geo-type (hotspot and urban). In the final calculation, the hotspot and urban results are combined to provide territory-wide figures.

The demand for voice services is included within the analysis of this study. Voice demand is included within the total demand being carried on the Hong Kong networks. Voice calls on 3G and 4G networks are carried over the same physical channel (spectrum) as data. This means that we are unable to calculate dropped calls as the provisioning on voice calls depends on network factors such as hand over parameters and priority given to voice. This is discussed further in Section 6.3 and Annex B.

The impact model calculates hotspot and territory-wide throughput as well as DCO for the different scenarios. The results are produced for each technology and operator in addition to the overall Hong Kong market. In Section 7.1, the following DCO results are analysed:

- total download DCO (hotspots and territory-wide) for each scenario and percentage changes[69] compared to the base case
- 3G download DCO (hotspots and territory-wide) for each scenario and percentage changes compared to the base case
- maximum changes in per-operator hotspot download DCO (total and 3G) for each scenario
- all the above results after implementing mitigation strategies.

A similar analysis is performed for throughput in Section 7.2. The findings of a sensitivity analysis are presented in Section 7.3.

7.1 Design Capacity Overage

Design Capacity Overage (DCO) is calculated as the percentage of demand unable to be met by the network design capacity. In this study, the network design capacity is assumed to be 75% of the total network capacity. Thus DCO is an indicator of the severity of the demand in excess of the network design capacity. A DCO figure of 100% indicates there is no network capacity available. A figure of 0% indicates that all demand is able to be met.

DCO = maximum of zero and (demand – utilisation × capacity) / demand

where utilisation is the network design utilisation as input in the *Assumptions* worksheet (and described in Section 6.2).

The DCO calculation takes into account network utilisation, which was set to 75% in this study. While DCO is below 25% total network capacity is still greater than demand. The model assumes that the trigger for service degradation is when demand reaches 75% of total network capacity, not when demand equals total network capacity. With a DCO figure of 40%, the demand is 25% greater than the total network capacity.[70] Network provisioning

69 All the percentage change values in Section 7 are accurate to one decimal place.

70 For example, if network capacity is 100 and demand is 125 (i.e. 25% greater than network capacity), then DOC is calculated as (125 – 75% × 100) / 125 = 40%.

is driven by busy hour traffic – note that this busy hour traffic does not take into account instantaneous peaks in traffic. Mobile traffic does not occur smoothly over time and is, in fact, very 'bursty'. The DCO calculation allows for the statistical and peak nature of mobile network traffic.

Total DCO levels

The territory-wide DCO results for the entire Hong Kong mobile network show that there is sufficient network design capacity to accommodate all demand under any scenario (Exhibit 7.1). This is because the total network DCO is calculated by summing the entire demand and supply across the 2G, 3G and 4G networks territory-wide. The 4G network capacity, in particular, overwhelms any deficit in design capacity that is present on the 3G hotspot networks (explained in more detail below) as there is significantly more capacity than demand on the 4G networks at present.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspot DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	5.2%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	5.2%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	5.2%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%
Territory-wide DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 7.1: *Total download DCO results [Source: Network Strategies]*

The DCO results for the hotspots show insufficient design capacity of 4.6–5.2% in 2018, however a capacity shortage of 5.2% is present in the base case with no change to 3G spectrum holding. The percentage point changes from the base case in hotspots show that in three of the five scenarios the DCO will decrease, meaning that operators will have less deficit in design capacity as compared to the base case (Exhibit 7.2). These results do not show significant differences between scenarios due to the aggregation of the network traffic over 2G, 3G and 4G hotspots. The DCO is unchanged from the base case in hotspots in scenarios 2a and 2b (the scenarios where spectrum re-assignment occurs within the 3G incumbent operators). This is because the hotspot network DCO is calculated by aggregating the entire demand and supply across the hotspots of the 2G, 3G and 4G networks. It is not the purpose of this total network DCO to indicate any design capacity deficit on any individual network of an operator.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (percentage point change)						
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%

Exhibit 7.2: *Percentage point changes in total download DCO compared with the base case [Source: Network Strategies]*

3G DCO levels

The impact model calculates DCO separately on the 2G, 3G and 4G networks in both the hotspots and territory-wide (that is, six separate results). The territory-wide 3G network does not show any deficit in design capacity, meaning that all demand is able to be met. The 3G hotspot network is the only one on which design capacity deficit is indicated during the modelling period. Our analysis shows that, even in the base case, without any change in 3G spectrum holding, design capacity deficit is present on the 3G hotspot network over the modelling period (Exhibit 7.3).

In 2013, the DCO in the base case is 16%. At a DCO level of 16% the total busy hour demand is below the total busy hour network capacity. The DCO increases to 37% in 2014, due to the increase in demand and the refarming of **[✂……]CI** of spectrum currently deployed for 3G services to 4G by **[✂………]CI** in 2014 (Exhibit 5.2), resulting in less 3G spectrum and hence increasing the deficit in design capacity in 3G hotspot network. The DCO figure starts to decrease gradually from 37% in 2014 to 33% in 2017 in the base case as traffic is migrated from the 3G to the 4G networks. In 2018 there is an increase because **[✂…...]CI** of spectrum currently deployed for 3G services is refarmed to 4G by **[✂…...........]CI**.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspot DCO (%)						
Base case	16.4%	36.7%	35.2%	31.2%	33.0%	40.1%
Scenario 2a	16.4%	36.7%	35.2%	31.2%	33.0%	40.1%
Scenario 2b	16.4%	36.7%	35.2%	31.2%	33.0%	40.1%
Scenario 2c	16.4%	36.7%	35.2%	30.4%	32.2%	39.3%
Scenario 2d	16.4%	36.7%	35.2%	29.7%	31.4%	38.6%
Scenario 3	16.4%	36.7%	35.2%	28.2%	29.9%	37.0%
Territory-wide DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 7.3: *3G download DCO results [Source: Network Strategies]*

The percentage point changes from the base case (Exhibit 7.4) indicate that DCO decreases from the base case on the 3G hotspot network as a whole under all scenarios except 2a and 2b (the scenario where 3G spectrum is re-assigned amongst the incumbent operators). Under scenarios 2c, 2d and 3, the percentage change is negative, meaning that the spectrum re-assignment has alleviated the deficit situation. Under scenario 3, the DCO is reduced by 3 percentage points from the base case. This result is due to the effect of increased total network capacity in the model because of an increase in total number of base stations.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (percentage point change)						
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	-0.7%	-0.8%	-0.8%
Scenario 2d	0.0%	0.0%	0.0%	-1.5%	-1.5%	-1.5%
Scenario 3	0.0%	0.0%	0.0%	-3.0%	-3.0%	-3.0%

Exhibit 7.4: *Percentage point changes in 3G hotspot download DCO compared with the base case [Source: Network Strategies]*

Per-operator hotspot DCO levels

The total network DCO results, do not intend to indicate the effect of various re-assignment scenarios on individual operators' hotspots.

Exhibit 7.5 shows the ranges of percentage point change in DCO from the base case that incumbent operators may experience. These figures are the maximum and minimum individual operator results under all of the different combinations for each scenario. These results have been presented in this manner to protect the confidentiality of the individual operators. In the calculations of the total DCO and 3G DCO in the previous two Sections, Scenarios 2c, 2d and 3 have included the potential additional capacity from China Mobile from 2016 onwards. The percentage point changes in the per-operator DCO below do not include China Mobile as it is not a 3G incumbent operator. Hence, the best and worst case per-operator percentage point changes in DCO refer to those amongst the four incumbent 3G operators only.

The ranges of percentage **point** change in DCO from the base case that incumbent operators may experience in hotspots show that in the best case a reduction of up to 2.7 percentage points over the modelling period is possible in scenario 2a (Exhibit 7.5). In the worst case an increase of up to 1.5 percentage point may occur in scenarios 2b.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	0.0%	0.0%	-2.7%	-2.0%	-1.6%
Worst case	0.0%	0.0%	0.0%	+0.8%	+0.8%	+0.7%
Scenario 2b						
Best case	0.0%	0.0%	0.0%	-2.2%	-1.7%	-1.4%
Worst case	0.0%	0.0%	0.0%	+1.5%	+1.3%	+0.7%
Scenario 2c						
Best case	0.0%	0.0%	0.0%	-0.5%	-0.8%	0.0%
Worst case	0.0%	0.0%	0.0%	+0.8%	+0.8%	+0.7%
Scenario 2d						
Best case	0.0%	0.0%	0.0%	-0.5%	-0.8%	0.0%
Worst case	0.0%	0.0%	0.0%	+0.8%	+0.8%	+0.7%
Scenario 3						
Best case	0.0%	0.0%	0.0%	-0.5%	-0.8%	0.0%
Worst case	0.0%	0.0%	0.0%	+0.8%	+0.8%	+0.7%

Exhibit 7.5: *Per operator total hotspot download DCO percentage point changes for each scenario (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

The ranges of percentage **point** change in DCO in the 3G hotspots from the base case show that the maximum increase in DCO from the base case under all scenarios is approximately 12 percentage points (for an operator with reduced spectrum holdings) and the maximum decrease is 9 points (for an operator gaining spectrum) (Exhibit 7.6). The impacts on the most and least affected operators are approximately the same in scenarios 2c, 2d, and 3 (the only difference is 0.3 percentage points in the best case of scenario 3 in 2016). In all scenarios the percentage point increase in DCO for the worst affected operator is greater than the decrease in DCO for the most improved operator.

Note that the tables of figures displayed in this exhibit do not show results for the same operator in each best and worst case, even on a year on year basis.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	0.0%	0.0%	-6.5%	-4.7%	-7.0%
Worst case	0.0%	0.0%	0.0%	+11.6%	+8.3%	+11.1%
Scenario 2b						
Best case	0.0%	0.0%	0.0%	-8.9%	-5.9%	-7.0%
Worst case	0.0%	0.0%	0.0%	+11.6%	+8.8%	+11.6%
Scenario 2c						
Best case	0.0%	0.0%	0.0%	0.0%	-4.7%	-7.0%
Worst case	0.0%	0.0%	0.0%	+11.6%	+6.1%	+3.8%
Scenario 2d						
Best case	0.0%	0.0%	0.0%	0.0%	-4.7%	-7.0%
Worst case	0.0%	0.0%	0.0%	+11.6%	+6.1%	+3.8%
Scenario 3						
Best case	0.0%	0.0%	0.0%	+0.3%	-4.7%	-7.0%
Worst case	0.0%	0.0%	0.0%	+11.6%	+6.1%	+3.8%

Exhibit 7.6: *Per operator 3G hotspot download DCO percentage point changes for each scenario (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

DCO levels with mitigation

This study considers the ability of operators to mitigate the effects of losing 2×5MHz of 3G spectrum holdings by refarming a portion of their 2G spectrum as this technology is gradually decommissioned. The mitigation strategies do not affect hotspot DCO until 2018 (the only circumstance in which DCO is indicated without mitigation). In 2018, the DCO for the base case is 5.2%, which is higher than the DCO for all five spectrum re-assignment scenarios, meaning that the re-assignment will not worsen the design capacity deficit being experienced in the base case (Exhibit 7.7). Scenario 2a (where spectrum re-assignment occurs amongst the 3G incumbent operators) has little benefit from mitigation measures. Scenario 3 shows the greatest difference (0.2 percentage points) between the case with and without mitigation (comparing Exhibit 7.1 and Exhibit 7.7).

Mitigation is assumed to be undertaken only by operators that lose 3G spectrum, and thus scenario 3 – in which all incumbent operators implement mitigation measures – is the most sensitive to mitigation measures.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspot DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	5.2%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	5.1%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	4.8%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	4.4%
Territory-wide DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 7.7: *Total download DCO with mitigation results [Source: Network Strategies]*

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (percentage point change)						
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%

Exhibit 7.8: *Percentage point changes in total download DCO with mitigation compared with the base case [Source: Network Strategies]*

The greatest impact of mitigation on DCO is in scenario 3 for the 3G hotspot network, with an improvement of approximately 10 percentage points for all years 2014 to 2018 (comparing Exhibit 7.3 and Exhibit 7.9) In 2016 of this scenario, the DCO for 3G hotspot network is calculated to be 28.2% without and 18% with mitigation. Under this scenario, all incumbent operators implement mitigation strategies. Note that the base case does not include any mitigation (i.e. there is no increase in 3G spectrum).

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspot DCO (%)						
Base case	16.4%	36.7%	35.2%	31.2%	33.0%	40.1%
Scenario 2a	16.4%	34.2%	32.8%	28.6%	30.5%	37.7%
Scenario 2b	16.4%	31.7%	30.3%	26.1%	28.0%	35.3%
Scenario 2c	16.4%	34.2%	32.8%	27.9%	29.7%	36.9%
Scenario 2d	16.4%	31.7%	30.3%	24.6%	26.5%	33.7%
Scenario 3	16.4%	26.7%	25.4%	18.0%	20.0%	27.4%
Territory-wide DCO (%)						
Base case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 7.9: *3G download DCO with mitigation results [Source: Network Strategies]*

Comparing the 3G hotspot DCO figures with mitigation to the base case scenario (Exhibit 7.10) shows the absolute decrease in DCO possible is at least two percentage points (in scenario 2a) and at most 13 (in scenario 3). These results show that mitigation can be a particularly effective method of decreasing DCO in 3G hotspots particularly comparing these with the results without mitigation (Exhibit 7.4). The negative percentage point changes under all five scenarios in Exhibit 7.10 show that the spectrum re-assignment scenarios will not worsen the design capacity deficit from the base case, and should alleviate the deficit in all scenarios.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (percentage point change)						
Scenario 2a	0.0%	-2.5%	-2.5%	-2.5%	-2.5%	-2.4%
Scenario 2b	0.0%	-5.0%	-4.9%	-5.1%	-5.0%	-4.8%
Scenario 2c	0.0%	-2.5%	-2.5%	-3.3%	-3.2%	-3.2%
Scenario 2d	0.0%	-5.0%	-4.9%	-6.6%	-6.5%	-6.3%
Scenario 3	0.0%	-10.0%	-9.8%	-13.2%	-13.0%	-12.7%

Exhibit 7.10: *Percentage point changes in 3G download DCO with mitigation compared with the base case [Source: Network Strategies]*

The maximum decrease in per operator hotspot DCO from the base case for the total network with mitigation is around 3 percentage points and the maximum increase is 1.5 percentage points (Exhibit 7.11). There is an improvement for all scenarios (comparing Exhibit 7.5 and Exhibit 7.11).

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	0.0%	0.0%	-3.1%	-2.2%	-1.6%
Worst case	0.0%	0.0%	0.0%	0.0%	0.0%	+0.3%
Scenario 2b						
Best case	0.0%	0.0%	0.0%	-3.1%	-2.2%	-1.6%
Worst case	0.0%	0.0%	0.0%	+1.5%	+1.3%	+0.7%
Scenario 2c						
Best case	0.0%	0.0%	0.0%	-3.1%	-2.2%	-1.6%
Worst case	0.0%	0.0%	0.0%	0.0%	0.0%	+0.3%
Scenario 2d						
Best case	0.0%	0.0%	0.0%	-3.1%	-2.2%	-1.6%
Worst case	0.0%	0.0%	0.0%	0.0%	0.0%	+0.3%
Scenario 3						
Best case	0.0%	0.0%	0.0%	-3.1%	-2.2%	-1.6%
Worst case	0.0%	0.0%	0.0%	0.0%	0.0%	+0.3%

Exhibit 7.11: *Per operator total hotspot download DCO percentage point changes with mitigation for each scenario (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

The effects of mitigation on individual operator's 3G hotspot networks are also shown (Exhibit 7.12). These results show the ranges of percentage point change in DCO from the base case that incumbent operators may experience by including mitigation.

The results show that the maximum increase in DCO from the base case under all scenarios is 11.6 points in 2018 for scenario 2b and the maximum decrease is around 24.5 points in 2014 and 2018 for all scenarios.

There is a significant improvement over the DCO results with no mitigation (comparing Exhibit 7.6 with Exhibit 7.12). For example, in scenario 3, without mitigation the 3G incumbent operator most affected is between four and twelve points worse off than the base case, with mitigation employed the most affected operator is up to two points worse off than the base case.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	-24.5%	-23.8%	-16.9%	-22.0%	-24.4%
Worst case	0.0%	0.0%	0.0%	+2.6%	+8.3%	+11.1%
Scenario 2b						
Best case	0.0%	-24.5%	-23.8%	-16.9%	-22.0%	-24.4%
Worst case	0.0%	0.0%	0.0%	+4.2%	+8.8%	+11.6%
Scenario 2c						
Best case	0.0%	-24.5%	-23.8%	-16.9%	-22.0%	-24.4%
Worst case	0.0%	0.0%	0.0%	+1.2%	0.0%	+1.6%
Scenario 2d						
Best case	0.0%	-24.5%	-23.8%	-16.9%	-22.0%	-24.4%
Worst case	0.0%	0.0%	0.0%	+1.2%	0.0%	+1.6%
Scenario 3						
Best case	0.0%	-24.5%	-23.8%	-16.9%	-22.0%	-24.4%
Worst case	0.0%	0.0%	0.0%	+1.2%	-3.5%	+1.6%

Exhibit 7.12: *Per operator 3G hotspot download DCO percentage point changes with mitigation for each scenario (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

7.2 Throughput

Throughput is calculated for each of the individual technologies (2G, 3G and 4G) and by geo-type (hotspot and urban). Throughput is defined as the minimum of network demand and capacity. If demand is greater than network capacity, only network capacity is able to be carried. If capacity is greater than demand, the throughput is equal to the demand.

Total throughput

Total market throughput is aggregated as a last step to produce the total network results (Exhibit 7.13 and Exhibit 7.14). The least impact on total market hotspot throughput is in scenario 2b. In this scenario total download throughput increases only in 2017 (Exhibit 7.13 and Exhibit 7.14). In most scenarios the total market throughput increases. This gain (both in the territory-wide and hotspot cases) is probably due to the effect of increased efficiency in spectrum re-assignment.

The increase in throughput in scenarios 2c, 2d and 3 is also a direct result of the assumption that the MNO without 3G spectrum will build additional base stations.

These throughput results are indicative of total market demand (rather than network capacity) as the DCO is zero for all years except 2018, when it increases to approximately 5% (Exhibit 7.1).

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Base case	21,694	31,178	49,912	70,147	88,426	105,556
Scenario 2a	21,694	31,178	49,912	70,266	88,604	105,666
Scenario 2b	21,694	31,178	49,912	70,151	88,541	105,596
Scenario 2c	21,694	31,178	49,912	70,128	88,578	105,720
Scenario 2d	21,694	31,178	49,912	70,123	88,820	106,003
Scenario 3	21,694	31,178	49,912	70,100	89,625	106,721
Territory-wide (Mbit/s)						
Base case	56,509	83,095	129,444	183,172	241,325	307,340
Scenario 2a	56,509	83,095	129,444	183,292	241,503	307,698
Scenario 2b	56,509	83,095	129,444	183,177	241,440	307,818
Scenario 2c	56,509	83,095	129,444	183,153	241,477	307,507
Scenario 2d	56,509	83,095	129,444	183,149	241,719	307,793
Scenario 3	56,509	83,095	129,444	183,126	242,524	308,519

Exhibit 7.13: *Total download throughput results [Source: Network Strategies]*

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Scenario 2a	0.0%	0.0%	0.0%	+0.2%	+0.2%	+0.1%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	+0.1%	0.0%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	+0.2%	+0.2%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	+0.4%	+0.4%
Scenario 3	0.0%	0.0%	0.0%	-0.1%	+1.4%	+1.1%
Territory-wide (Mbit/s)						
Scenario 2a	0.0%	0.0%	0.0%	+0.1%	+0.1%	+0.1%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	0.0%	+0.2%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	+0.1%	+0.1%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	+0.2%	+0.1%
Scenario 3	0.0%	0.0%	0.0%	0.0%	+0.5%	+0.4%

Exhibit 7.14: *Percentage changes in total download throughput compared with the base case [Source: Network Strategies]*

Total market throughput is steadily increasing over the modelling period (in Exhibit 7.15 for hotspots and Exhibit 7.16 for territory-wide) in line with our demand projections (as discussed in Section 4.2) These graphs illustrate that the proportional differences between the scenarios is extremely small when considering the download throughput for the whole of the Hong Kong market.

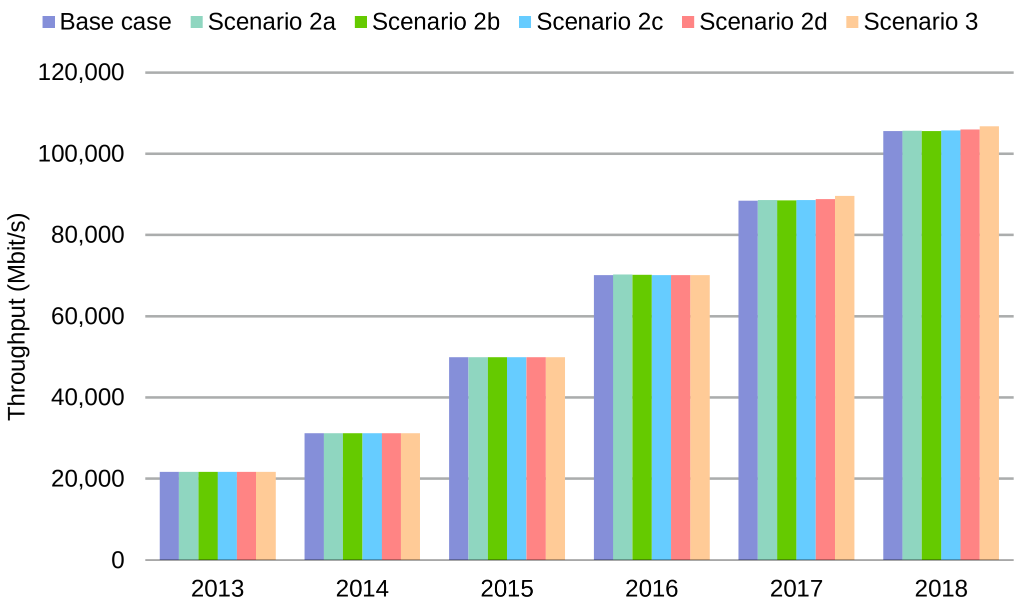

Exhibit 7.15: *Total hotspot download throughput [Source: Network Strategies]*

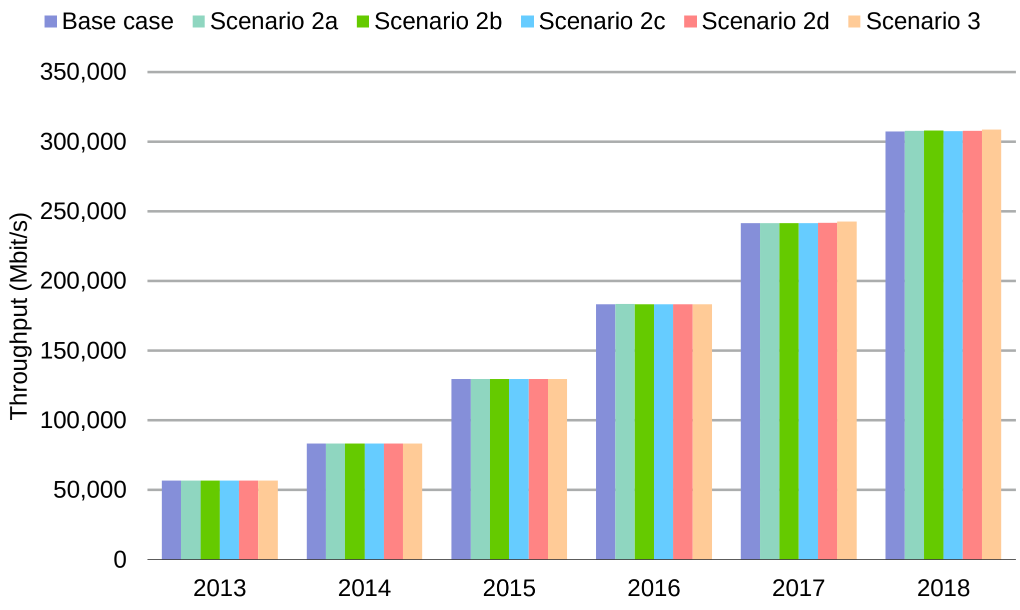

Exhibit 7.16: *Territory-wide total download throughput [Source: Network Strategies]*

3G throughput

The impact model results show that the greatest impact on 3G throughput is in scenario 3 (Exhibit 7.17 and Exhibit 7.18). In this scenario, the greatest impact is indicated in 2018, which shows around 6% and 2% increase in total throughput for hotspots and territory-wide respectively. Note that this is a total effect across the entirety of the 3G networks for all operators (including the MNO without 3G spectrum): it does not account for the individual effects on each operator's network, which is discussed in the following section.

This analysis shows an improvement in total throughput from the base case in 2017 and 2018 for all of the five scenarios. In particular, scenario 2a, where there is spectrum re-assignment within the incumbent operators only, shows an increase in total throughput for the modelling period, which most likely represents more efficient spectrum re-assignment amongst operators. Scenario 2b, where there is greater spectrum re-assignment within the incumbent operators, shows a smaller improvement in throughput for the entire modelling period in the hotspots, which likely indicates that this degree of spectrum re-assignment is probably not efficient in terms of throughput.

This analysis shows an improvement in total throughput in 3G hotspots and territory-wide from the base case in two of the five scenarios for 2016 and in all five scenarios for 2017–18. In particular, scenario 2a, where there is spectrum re-assignment within the incumbent operators only, shows an increase in total throughput for 2016–18, which most likely represents more efficient spectrum re-assignment amongst operators. Scenario 2b, where there is greater spectrum re-assignment within the incumbent operators, shows a smaller improvement in 3G hotspot throughput for the entire modelling period, which likely indicates that this degree of spectrum re-assignment is probably not efficient in terms of throughput.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Base case	17,116	18,603	19,382	19,608	19,737	18,388
Scenario 2a	17,116	18,603	19,382	19,727	19,915	18,497
Scenario 2b	17,116	18,603	19,382	19,613	19,852	18,427
Scenario 2c	17,116	18,603	19,382	19,589	19,888	18,551
Scenario 2d	17,116	18,603	19,382	19,585	20,131	18,834
Scenario 3	17,116	18,603	19,382	19,561	20,936	19,553
Territory-wide (Mbit/s)						
Base case	45,095	51,688	53,154	52,377	53,445	52,325
Scenario 2a	45,095	51,688	53,154	52,497	53,622	52,683
Scenario 2b	45,095	51,688	53,154	52,382	53,560	52,803
Scenario 2c	45,095	51,688	53,154	52,358	53,596	52,492
Scenario 2d	45,095	51,688	53,154	52,354	53,839	52,778
Scenario 3	45,095	51,688	53,154	52,331	54,644	53,503

Exhibit 7.17: *3G download throughput results [Source: Network Strategies]*

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Scenario 2a	0.0%	0.0%	0.0%	+0.6%	+0.9%	+0.6%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	+0.6%	+0.2%
Scenario 2c	0.0%	0.0%	0.0%	-0.1%	+0.8%	+0.9%
Scenario 2d	0.0%	0.0%	0.0%	-0.1%	+2.0%	+2.4%
Scenario 3	0.0%	0.0%	0.0%	-0.2%	+6.1%	+6.3%
Territory-wide (Mbit/s)						
Scenario 2a	0.0%	0.0%	0.0%	+0.2%	+0.3%	+0.7%
Scenario 2b	0.0%	0.0%	0.0%	0.0%	+0.2%	+0.9%
Scenario 2c	0.0%	0.0%	0.0%	0.0%	+0.3%	+0.3%
Scenario 2d	0.0%	0.0%	0.0%	0.0%	+0.7%	+0.9%
Scenario 3	0.0%	0.0%	0.0%	-0.1%	+2.2%	+2.3%

Exhibit 7.18: *Percentage changes in 3G download throughput compared with the base case [Source: Network Strategies]*

Throughput in the 3G hotspot network increases for the first five years (2013–17), and decreases in 2018 (Exhibit 7.19). This is due to the assumptions regarding 4G overflow into 3G.[71] The model assumes that as the 4G network becomes more mature it is upgraded to LTE-A and thus may carry voice traffic; furthermore once the 4G coverage footprint matches that of the 3G network, less 4G traffic will need to be carried on the 3G network.

The percentage changes in throughput between the base case and the scenarios are larger in the 3G hotspot network than the 3G territory-wide network. For example in scenario 3 during 2018, an increase of 6% in the 3G hotspot network corresponds to an increase of 2% in the 3G territory-wide network. This is because the 3G hotspot network is already operating close to spectral capacity (i.e. the network is carrying as much traffic as possible – refer to Exhibit 7.3) and the model is therefore very sensitive to any change in spectrum availability (our sensitivity analysis is discussed in more detail in Section 7.3 of this report). This means that any increase or decrease in a single operator’s spectrum holdings will have significant impacts on its 3G hotspot network.

71 Overflow from the 4G to the 3G network is described in more detail in Section 6.2 of this report.

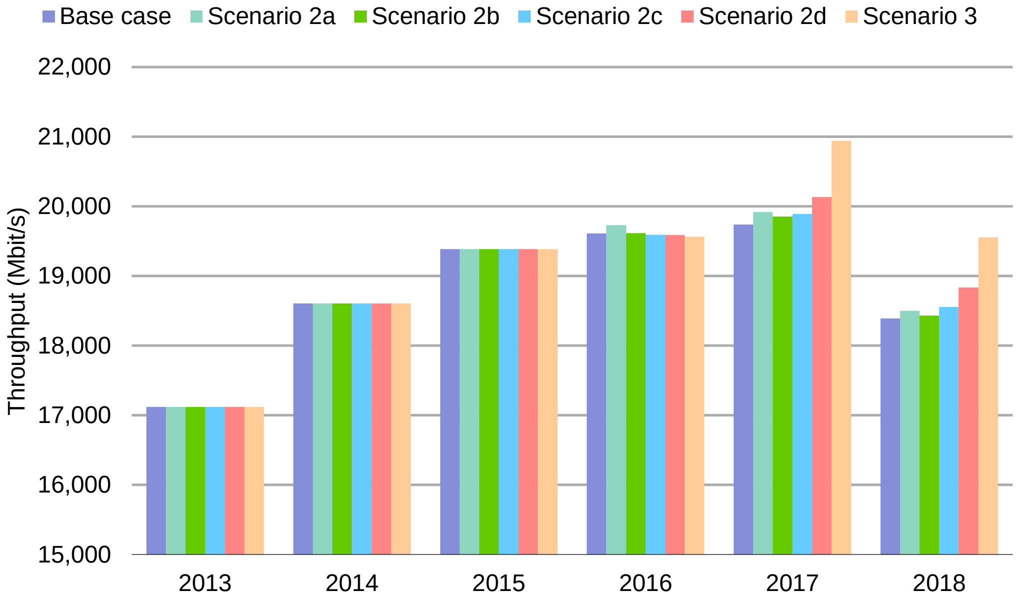

Exhibit 7.19: *3G hotspot download throughput [Source: Network Strategies]*

Per-operator hotspot throughput

The total network throughput figures do not provide any insight into the effect of various spectrum re-assignment scenarios on individual operators' hotspots, and therefore the end customers themselves. Exhibit 7.20 shows the ranges of percentage change in throughput from the base case that incumbent operators may experience. These figures are the maximum and minimum individual operator results under all of the different combinations for each scenario. These results have been presented in this manner to protect the confidentiality of the individual operators. In the calculations of the total throughput and 3G throughput in the previous two Sections, Scenarios 2c, 2d and 3 have included the potential additional throughput from the MNO without 3G spectrum from 2016 onwards. The percentage point increases in the per-operator throughput below do not include the MNO without 3G spectrum as it is not a 3G incumbent operator. Hence, the best and worst case per-operator percentage point changes in throughput refer to those amongst the four incumbent 3G operators only.

These figures show the best and worst experiences in busy hour total hotspot throughput possible for the subscribers of any particular incumbent operator. The extreme scenario (scenario 3) shows that even for the incumbent operator least affected, the throughput to subscribers in its hotspots during busy hour is 5–6% worse than in the base case. For the incumbent operator most affected, the throughput to subscribers in its hotspots during busy hour is 8–12% worse.

For scenarios 2a and 2b (where spectrum re-assignment occurs solely within the 3G incumbent operators), the subscribers of the most affected incumbent operator will experience a decrease in throughput of 8–12% in the hotspots during busy hour, whereas the subscribers of the least affected operator will experience an increase in throughput of 8-12% during the busy hour.

A throughput decrease of, say, 10% means that all subscribers of the affected operator attempting to use time-critical services such as video streaming at the hotspot network during busy hour may experience delay, and depending on how many simultaneous users on the hotspot network, may at some instances not able to use these services during the busy hour.[72] This drop in throughput should have little impact to non-time critical applications such as WhatsApp, Google Map and web browsing, although some delay in these services may be experienced.

In the case of throughput one operator's gain is another operator's loss (scenarios 2a and 2b, where spectrum reallocation occurs within the 3G incumbent operators).

72 The data provided to Network Strategies by MNOs indicated a download versus upload proportion of approximately **[✂…]CI**, which is quite high by international standards, and suggests a high usage of asymmetric services, such as video, by Hong Kong subscribers.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	0.0%	0.0%	+11.6%	+9.6%	+8.3%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-8.3%
Scenario 2b						
Best case	0.0%	0.0%	0.0%	+11.6%	+9.6%	+8.3%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-8.3%
Scenario 2c						
Best case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-8.3%
Scenario 2d						
Best case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-8.3%
Scenario 3						
Best case	0.0%	0.0%	0.0%	-6.2%	-5.1%	-4.7%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-8.3%

Exhibit 7.20: *Percentage changes in per operator total hotspot download throughput (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

Per-operator 3G hotspot throughput

The impacts on the 3G hotspot throughput on individual operators' networks are greater than those across all hotspots (Exhibit 7.21).

These figures show the best and worst experiences in 3G busy hour hotspot throughput possible for the subscribers of any particular incumbent operator. The extreme scenario (scenario 3) shows that for the incumbent operator least affected, the throughput for subscribers in its 3G hotspots during busy hour is 22% worse than in the base case. For the incumbent operator most affected, the throughput for subscribers in its 3G hotspots during busy hour is 26–33% worse.

The scenarios with the least impact on individual operators are scenarios 2a and 2b. In these scenarios, the 3G subscribers of the incumbent operator with additional spectrum holdings will experience an increase in throughput at 3G hotspots during the busy hour of 32–44%. The subscribers of the most affected incumbent operator will experience a reduction in throughput of 26–33% at 3G hotspots during the busy hour.

In the case of throughput the operators' gains and losses are asymmetric, as with DCO (Exhibit 7.6). Scenarios 2a and 2b, where spectrum reallocation occurs within the 3G incumbent operators, show the best individual operator results.

The tables of figures displayed in this exhibit do not show results for the same operator in each best and worst case, even on a year on year basis, as previously discussed.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	0.0%	0.0%	+37.4%	+44.2%	+39.6%
Worst case	0.0%	0.0%	0.0%	-25.9%	-27.6%	-33.1%
Scenario 2b						
Best case	0.0%	0.0%	0.0%	+32.0%	+41.9%	+39.6%
Worst case	0.0%	0.0%	0.0%	-25.9%	-27.6%	-33.1%
Scenario 2c						
Best case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-25.9%	-27.6%	-33.1%
Scenario 2d						
Best case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-25.9%	-27.6%	-33.1%
Scenario 3						
Best case	0.0%	0.0%	0.0%	-22.0%	-22.0%	-22.0%
Worst case	0.0%	0.0%	0.0%	-25.9%	-27.6%	-33.1%

Exhibit 7.21: *Percentage changes in per operator 3G hotspot download throughput (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

Total throughput with mitigation

In all scenarios, the mitigation strategies assumed in the impact model increase the throughput (Exhibit 7.22 and Exhibit 7.23). Presented here are the results of mitigation measures on hotspots and territory-wide across all networks. The increase in throughput with mitigation improves throughput further under all scenarios.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Base case	21,694	31,178	49,912	70,147	88,426	105,556
Scenario 2a	21,694	31,499	50,214	70,794	89,031	105,782
Scenario 2b	21,694	31,820	50,516	71,207	89,396	105,828
Scenario 2c	21,694	31,499	50,214	70,655	89,005	105,836
Scenario 2d	21,694	31,820	50,516	71,179	89,676	106,235
Scenario 3	21,694	32,463	51,119	72,211	91,336	107,186
Territory-wide (Mbit/s)						
Base case	56,509	83,095	129,444	183,172	241,325	307,340
Scenario 2a	56,509	83,416	129,745	183,819	241,930	307,814
Scenario 2b	56,509	83,737	130,047	184,232	242,295	308,051
Scenario 2c	56,509	83,416	129,745	183,681	241,904	307,623
Scenario 2d	56,509	83,737	130,047	184,204	242,575	308,025
Scenario 3	56,509	84,380	130,650	185,236	244,235	308,983

Exhibit 7.22: *Total download throughput with mitigation results [Source: Network Strategies]*

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Scenario 2a	0.0%	+1.0%	+0.6%	+0.9%	+0.7%	+0.2%
Scenario 2b	0.0%	+2.1%	+1.2%	+1.5%	+1.1%	+0.3%
Scenario 2c	0.0%	+1.0%	+0.6%	+0.7%	+0.7%	+0.3%
Scenario 2d	0.0%	+2.1%	+1.2%	+1.5%	+1.4%	+0.6%
Scenario 3	0.0%	+4.1%	+2.4%	+2.9%	+3.3%	+1.5%
Territory-wide (Mbit/s)						
Scenario 2a	0.0%	+0.4%	+0.2%	+0.4%	+0.3%	+0.2%
Scenario 2b	0.0%	+0.8%	+0.5%	+0.6%	+0.4%	+0.2%
Scenario 2c	0.0%	+0.4%	+0.2%	+0.3%	+0.2%	+0.1%
Scenario 2d	0.0%	+0.8%	+0.5%	+0.6%	+0.5%	+0.2%
Scenario 3	0.0%	+1.5%	+0.9%	+1.1%	+1.2%	+0.5%

Exhibit 7.23: *Percentage changes in total download throughput with mitigation compared with the base case [Source: Network Strategies]*

Throughput in 3G network with mitigation

The mitigation strategies assumed in the impact model increase 3G throughput further under all scenarios (Exhibit 7.24 and Exhibit 7.25). Presented here are the results of mitigation measures on the 3G network both territory-wide and for hotspots.

The impact of mitigation is less territory-wide, where throughput is generally not constrained by capacity. This is illustrated in the DCO results (Exhibit 7.3), which show no capacity deficit in the territory-wide networks (indicating that throughput is equal to demand) and deficit in the hotspot figures (indicating that throughput is equal to capacity).

Mitigation is assumed to be undertaken only by operators that lose 2×5MHz of 3G spectrum, as noted previously, and thus scenario 3 – in which all incumbent operators implement mitigation measures – is the most sensitive to mitigation measures.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Base case	17,116	18,603	19,382	19,608	19,737	18,388
Scenario 2a	17,116	18,924	19,684	19,979	20,074	18,628
Scenario 2b	17,116	19,245	19,985	20,117	20,171	18,689
Scenario 2c	17,116	18,924	19,684	19,841	20,048	18,682
Scenario 2d	17,116	19,245	19,985	20,089	20,451	19,096
Scenario 3	17,116	19,888	20,589	20,570	21,576	20,077
Territory-wide (Mbit/s)						
Base case	45,095	51,688	53,154	52,377	53,445	52,325
Scenario 2a	45,095	52,009	53,456	52,749	53,782	52,814
Scenario 2b	45,095	52,331	53,758	52,886	53,879	53,065
Scenario 2c	45,095	52,009	53,456	52,610	53,756	52,623
Scenario 2d	45,095	52,331	53,758	52,858	54,158	53,040
Scenario 3	45,095	52,973	54,361	53,339	55,283	54,028

Exhibit 7.24: *3G download throughput with mitigation results [Source: Network Strategies]*

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Hotspots (Mbit/s)						
Scenario 2a	0.0%	+1.7%	+1.6%	+1.9%	+1.7%	+1.3%
Scenario 2b	0.0%	+3.5%	+3.1%	+2.6%	+2.2%	+1.6%
Scenario 2c	0.0%	+1.7%	+1.6%	+1.2%	+1.6%	+1.6%
Scenario 2d	0.0%	+3.5%	+3.1%	+2.5%	+3.6%	+3.9%
Scenario 3	0.0%	+6.9%	+6.2%	+4.9%	+9.3%	+9.2%
Territory-wide (Mbit/s)						
Scenario 2a	0.0%	+0.6%	+0.6%	+0.7%	+0.6%	+0.9%
Scenario 2b	0.0%	+1.2%	+1.1%	+1.0%	+0.8%	+1.4%
Scenario 2c	0.0%	+0.6%	+0.6%	+0.4%	+0.6%	+0.6%
Scenario 2d	0.0%	+1.2%	+1.1%	+0.9%	+1.3%	+1.4%
Scenario 3	0.0%	+2.5%	+2.3%	+1.8%	+3.4%	+3.3%

Exhibit 7.25: *Percentage changes in 3G download throughput with mitigation compared with the base case [Source: Network Strategies]*

Per-operator hotspot throughput with mitigation

The total network throughput figures do not provide any insight into the effect of various spectrum re-assignment scenarios on individual operators' hotspots. A subscriber is connected to only one network and therefore only the performance of that network will affect that customer. The total network figures are calculated by aggregating all the individual throughput figures – therefore this overall average throughput does not indicate any increase or decrease for individual networks.

Exhibit 7.26 shows the ranges of percentage change in hotspot throughput from the base case that incumbent operators may experience when taking into account mitigation measures.

These figures show the best and worst experiences in busy hour hotspot throughput possible for the subscribers of any particular incumbent operator. The extreme scenario (scenario 3) shows that for the 3G incumbent operator least affected, the throughput for subscribers in its hotspots during busy hour is 1–3% worse than in the base case. For the 3G incumbent operator most affected, the throughput for subscribers in its hotspots during busy hour is 8–12% worse than the base case.

The impact of spectrum re-assignment including mitigation measures on the hotspot throughput on individual operators' networks is minimal for scenarios 2a, 2b, 2c and 2d and the only improvement in performance is in 2018.

The model assumes that mitigation measures are not employed by the operators with increased 3G spectrum holdings in the 1.9–2.2GHz spectrum band and therefore the operators with the greatest increase in throughput are generally unchanged from the case without mitigation.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	+14.5%	+9.2%	+11.6%	+9.6%	+8.3%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-7.7%
Scenario 2b						
Best case	0.0%	+14.5%	+9.2%	+11.6%	+9.6%	+8.3%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-7.7%
Scenario 2c						
Best case	0.0%	+14.5%	+9.2%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-7.7%
Scenario 2d						
Best case	0.0%	+14.5%	+9.2%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-7.7%
Scenario 3						
Best case	0.0%	+14.5%	+9.2%	-2.5%	-1.9%	-1.3%
Worst case	0.0%	0.0%	0.0%	-11.6%	-9.6%	-7.7%

Exhibit 7.26: *Percentage changes in per operator total hotspot download throughput with mitigation (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

Per-operator 3G hotspot throughput with mitigation

The impact on the 3G hotspot throughput on individual operators' networks is greater than those on across all hotspots. The ranges of percentage change in 3G hotspot throughput with mitigation from the base case that incumbent operators may experience are shown in Exhibit 7.27.

These figures show the best and worst experiences in 3G busy hour hotspot throughput possible for the subscribers of any particular incumbent operator. The extreme scenario (scenario 3) shows that for the incumbent operator least affected, the throughput to subscribers in its 3G hotspots during busy hour is 9–15% worse than in the base case for 2016–18. For the incumbent operator most affected, the throughput to subscribers in its hotspots during busy hour is 25–33% worse than the base case.

Description	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Scenario 2a						
Best case	0.0%	+23.1%	+21.7%	+37.4%	+44.2%	+39.6%
Worst case	0.0%	0.0%	0.0%	-24.7%	-27.6%	-33.1%
Scenario 2b						
Best case	0.0%	+23.1%	+21.7%	+32.0%	+41.9%	+39.6%
Worst case	0.0%	0.0%	0.0%	-24.7%	-27.6%	-33.1%
Scenario 2c						
Best case	0.0%	+23.1%	+21.7%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-24.7%	-27.6%	-33.1%
Scenario 2d						
Best case	0.0%	+23.1%	+21.7%	0.0%	0.0%	0.0%
Worst case	0.0%	0.0%	0.0%	-24.7%	-27.6%	-33.1%
Scenario 3						
Best case	0.0%	+23.1%	+21.7%	-9.4%	-13.3%	-15.4%
Worst case	0.0%	0.0%	0.0%	-24.7%	-27.6%	-33.1%

Exhibit 7.27: *Percentage changes in per operator 3G hotspot download throughput with mitigation (compared with the base case) for the four incumbent operators [Source: Network Strategies]*

7.3 Sensitivity analysis

We performed sensitivity testing of the model to analyse the effect on the DCO and throughput results when key inputs to the model are changed.

In all the cases of sensitivity testing, we found that hotspot DCO is more sensitive to those key parameters than territory-wide DCO (Exhibit 7.28). Also, the increase in total hotspot DCO is higher than 3G hotspot DCO. However, the decrease in total hotspot DCO is not greater than 5.2% because it is limited by the amount of DCO already present. As the maximum total hotspot DCO present is 5.2% (shown in Exhibit 7.1), a reduction of 5.2% indicates that there is no longer any deficit in design capacity.

Projection or assumption changed	*Hotspot*		*Territory-wide*	
	3G	*Total*	*3G*	*Total*
Number of base stations				
+10%	-8.4%	-5.2%	0.0%	0.0%
-10%	+8.4%	+9.5%	0.0%	0.0%
Demand (total busy hour traffic)				
+10%	+7.5%	+8.7%	0.0%	0.0%
-10%	-9.1%	-5.2%	0.0%	0.0%
Spectral efficiency				
+10%	-6.1%	-5.2%	0.0%	0.0%
-10%	+6.4%	+9.4%	0.0%	0.0%

Note: The maximum total hotspot DCO was 5.2% (as shown in Exhibit 7.1) and hence, the decrease cannot be greater than 5.2% even though the impact might be greater.

Exhibit 7.28: *Percentage point changes in download DCO due to increase/decrease in projections and assumptions [Source: Network Strategies]*

The main findings on sensitivity of throughput results (shown in Exhibit 7.29) are summarised below:

- **Base station projections** – Hotspot throughputs are more sensitive to base station projections than territory-wide throughputs. Also, 3G throughputs are more sensitive than total throughputs.
- **Demand projections** – Territory-wide throughputs are more sensitive to demand projections than hotspot throughputs.
- **Spectral efficiency assumptions** – Hotspot 3G throughputs are more sensitive to spectral efficiency assumptions whereas the total territory-wide throughputs are less sensitive.

Projection or assumption changed	*Hotspot*		*Territory-wide*	
	3G	*Total*	*3G*	*Total*
Number of base stations				
+10%	+8.0%	+4.9%	+4.5%	+2.0%
-10%	-10.0%	-6.1%	-5.3%	-2.3%
Demand (total busy hour traffic)				
+10%	+2.4%	+6.5%	+7.1%	+8.6%
-10%	-4.5%	-7.6%	-7.9%	-9.1%
Spectral efficiency				
+10%	+8.2%	+5.5%	+5.2%	+3.4%
-10%	-10.0%	-6.6%	-5.8%	-3.8%

Exhibit 7.29: *Percentage changes in download throughput due to increase/decrease in projections and assumptions [Source: Network Strategies]*

Annex A: Summary of spectrum holdings

Spectrum holdings of the five MNOs (CSL Ltd, Hutchison, HKT, SmarTone and China Mobile) and 21 ViaNet as at April 2013 are shown below (Exhibit A.1).

Current deployment	*Expiry year*	*Paired spectrum (MHz)*					*Unpaired spectrum (MHz)*		
		850 MHz	*850/900 MHz*	*1800 MHz*	*1.9-2.2 GHz*	*2.5-2.6 GHz*	*700 MHz*	*2[4] GHz*	*2.3 GHz*
CSL									
GSM & 3G	2021		16.6						
GSM & 4G	2021			46.4					
3G	2016				29.6				
Not deployed	2016							5	
4G-LTE	2024					30			
Likely 4G	2028[3]					10			
Total			16.6	46.4	29.6	40		5	
Hutchison									
GSM[1]	2020		16.6						
GSM[2]	2021			23.2					
3G	2016				29.6				
Not deployed	2016							5	
3G	2026		10						
Likely 4G	2027								30
4G-LTE	2024					15[7]			
Likely 4G	2028[3]					5[7]			
Total			26.6	23.2	29.6	20		5	30

Exhibit A.1: *Radio spectrum holding and use [Source: OFCA]*

Current deployment	*Expiry year*	*Paired spectrum (MHz)*					*Unpaired spectrum (MHz)*		
		850 MHz	*850/900 MHz*	*1800 MHz*	*1.9-2.2 GHz*	*2.5-2.6 GHz*	*700 MHz*	*2[4] GHz*	*2.3 GHz*
HKT									
GSM[2]	2021			23.2					
GSM	2021			3.2					
3G	2016				29.6				
Not deployed	2016							5	
CDMA2000	2023	15							
4G-LTE	2024					15[7]			
Likely 4G	2028[3]					5[7]			
Total		15		26.4	29.6	20		5	
SmarTone									
GSM[1]	2021		16.6						
GSM & 4G	2021			23.2					
GSM	2021			3.2					
3G	2026		10						
3G	2016				29.6				
Undeployed	2016							5	
Likely 4G	2028[3]					20			
Total			26.6	26.4	29.6	20		5	
China Mobile									
GSM[2]	2021			20					
GSM	2021			3.2					
GSM	2021			3.2					
4G-LTE	2024					30			
Likely 4G[8]	2027								30
CMMB[6]	2025						8		
Likely 4G	2028[3]					10			
Total				26.4		40	8		30

Exhibit A.1 (cont):*Radio spectrum holding and use [Source: OFCA]*

Current deployment	*Expiry year*	*Paired spectrum (MHz)*					*Unpaired spectrum (MHz)*		
		850 MHz	*850/900 MHz*	*1800 MHz*	*1.9-2.2 GHz*	*2.5-2.6 GHz*	*700 MHz*	*2[4] GHz*	*2.3 GHz*
21 ViaNet									
Fixed[5]	2027								30
TOTAL		15	69.8	148.8	118.4	140	8	20	90

Note 1: Some spectrum could be refarmed for 3G.

Note 2: Some spectrum could be refarmed for 4G.

Note 3: The 2.5-2.6GHz spectrum auctioned in March 2013 has been assigned for a period of 15 years from the date of issue of the licences in mid 2013.

Note 4: The unpaired lots in the 2GHz band was assigned together with the paired lots in the 1.9-2.2GHz band but not deployed by any operator due to lack of commercially appealing technology for the band.

Note 5: Could be redeployed for mobile services.

Note 6: China Mobile Multimedia Broadcasting, mobile television and multimedia standard.

Note 7: 40MHz in the 2.5-2.6GHz band is shared by Hutchison and HKT through a joint venture under Genius Brand Limited.

Note 8: 4G base stations already deployed but service has not been launched.

Exhibit A.1 (cont):*Radio spectrum holding and use [Source: OFCA]*

Annex B: Responses to operator feedback

Network Strategies developed preliminary results by operator from the impact model using data sourced from each operator. As this data is confidential, our assumptions and preliminary results were presented to each individual operator and an opportunity was provided for both verbal and written feedback. Below we summarise our responses to all issues raised by individual operators during this process. In doing so we have not identified the operators, and we have not reproduced any confidential data.

The issues are grouped below with the following themes:

- spectral efficiency assumptions
- other assumptions
- data issues
- impact model design
- preliminary results
- other issues.

B.1 Assumptions

Operator comment	*Network Strategies response*
[✂……]CI	We have decided to make the assumption of no spectral efficiency improvement in the 3G networks due to operator consensus and our experience regarding 3G technologies.
[✂……]CI	We have used the median value out of the different values suggested by different operators for 3G spectral efficiency.
[✂……]CI	The assumptions for spectral efficiency of LTE-A were changed in the model to reflect this feedback.
[✂……]CI	The spectral efficiency of 4G technology was modified to be consistent with operator feedback.

Exhibit B.1: *Operator comments and Network Strategies response on spectral efficiency assumptions [Source: operators, Network Strategies]*

Operator comment	*Network Strategies response*
[✂………]CI	These spectral efficiency values were incorporated in the model.

Exhibit B.1(cont): *Operator comments and Network Strategies response on spectral efficiency assumptions [Source: operators, Network Strategies]*

Operator comment	*Network Strategies response*
[✂……………………………………………………………………………………………………]CI	Network blocking probability percentage was changed in the model to reflect this feedback.
[✂………]CI	We modified the base station assumptions in the model in line with operator feedback.
[✂……]CI	We modified the base station assumptions in the model in line with operator feedback.
[✂……]CI	Incumbent operators' existing spectrum refarming plans have been included in the model.
[✂………………………………………………………]CI	Network utilisation percentage was changed in the model to reflect this feedback.
[✂……]CI	This information was included in our calculations of average RRUs per base station per MHz.
[✂……]CI	The details on quality of service are addressed in Section 6.3.

Exhibit B.2: *Operator comments and Network Strategies response on other assumptions [Source: operators, Network Strategies]*

B.2 Data issues

Operator comment	*Network Strategies response*
[✂……]CI	The base station numbers have been modified in the model to be consistent with operator feedback.
[✂……]CI	Final version of the model incorporates 3G demand correctly, including MVNO demand.
[✂…………………………………………………………………]CI	The base station numbers have been modified in the model to be consistent with operator feedback.
[✂……………………………………………………………………]CI	Network Strategies has thoroughly checked all operator input and ensured that it has been incorporated correctly.
[✂……]CI	These values for average number of transceivers were incorporated in the model.
[✂……………………………………………………………………………………………………]CI	These values for average number of transceivers were incorporated in the model.
[✂……………………………………………………………………]CI	Base station numbers were changed in the model to reflect this feedback.
[✂…………………………………………………………]CI	Network Strategies has modified the base station assumptions in the model in line with operator feedback.

Exhibit B.3: *Operator comments and Network Strategies response on data issues [Source: operators, Network Strategies]*

B.3 Model design

Operator comment	*Network Strategies response*
[✂……………………………………………………………………………………………………]CI	Indicators of customer experience are discussed in Section 6.3.
[✂………]CI	The model uses Design Capacity Overage (DCO), which is defined as the maximum of zero and (demand – 75% of capacity) / (demand). This topic is addressed in Section 7.1.The figure of 75% is a standard engineering utilisation parameter used in models by other regulators (such as Ofcom[73]), recommended by other operators during the consultation process of this study and is in line with our network dimensioning experience. DCO does not indicate individual customer experience; rather it is a measure of the degree to which demand is greater than capacity. This model is not designed to reflect an individual customer's experience. Instead, the model assesses the impact on individual operators as well as for the aggregate experience across the 3G network and the Hong Kong entire mobile network, both territory-wide and in hotspots.
[✂………]CI	Same as previous response.

Exhibit B.4: *Operator comments and Network Strategies response on model design [Source: operators, Network Strategies]*

73 Ofcom mobile LRIC model, available at http://www.ofcom.org.uk/static/wmvct-model/model-2011.html, March 2011.

Operator comment	*Network Strategies response*
[✂………………………………………]CI	These formulae are the ones used for the relevant calculations in the model.
[✂………………………………………]CI	The definition of the congestion metric (DCO) was modified to address this feedback.
[✂………………………………………]CI	The model assesses the impact across the 3G network and the Hong Kong entire mobile network, both territory-wide and in hotspots.
[✂………………………………………]CI	Quality of service parameters are discussed in Section 6.3 of the report.

Exhibit B.4 (cont): *Operator comments and Network Strategies response on model design [Source: operators, Network Strategies]*

Operator comment	*Network Strategies response*
[✂…………………………………]CI	The model assesses the impact across the 3G network and the Hong Kong entire mobile network, both territory-wide and in hotspots.
[✂…………………………………]CI	The base station numbers used in the model take account of progressive network roll-out.
[✂…………………………………]CI	The algorithms in the model are consistent with these calculations.

Exhibit B.4 (cont): *Operator comments and Network Strategies response on model design [Source: operators, Network Strategies]*

B.4 Preliminary results

Operator comment	*Network Strategies response*
[✂………………………………………………]CI	The final version of the model is producing results that are consistent between individual operators as well as consistent with a network total to within an acceptable margin of error.
[✂………………………………………………]CI	The calculations in the model have been modified to reflect this feedback on capacity and traffic.
[✂………………………………………………]CI	The final version of the model is producing results that are consistent between individual operators as well as consistent with a network total to within an acceptable margin of error.
[✂………………………………]CI	No separate results are produced for the MTR as information disaggregated to a sufficient level to enable us to do so was not provided by the operators. The definition of DCO (used to assess congestion) is detailed in Section 6.3.
[✂………………………………………………]CI	The final version of the model is producing results that are consistent between individual operators as well as consistent with a network total to within an acceptable margin of error.

Exhibit B.5: *Operator comments and Network Strategies response on preliminary results [Source: operators, Network Strategies]*

Operator comment	*Network Strategies response*
[✂…………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… ………………………]CI	The model results are particularly sensitive to demand forecasts, base station number projections and network assumptions. As such these results are a reflection of the input data provided to Network Strategies from the Hong Kong MNOs.
[✂…………………………………………………… …………………………………………………………… …………………………………………………………… …]CI	For every likely scenario the territory-wide total and 3G networks do not show any deficit in design capacity, meaning that all demand is able to be met.

Exhibit B.5 (cont): *Operator comments and Network Strategies response on preliminary results [Source: operators, Network Strategies]*

B.5 Other

Operator feedback	*Network Strategies response*
[✂…………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………]CI	The worst case or extreme scenario (scenario 3) has been included in the analysis.

Exhibit B.6: *Operator comments and Network Strategies response on other issues [Source: operators, Network Strategies]*