Impact assessment of re-auction of 2.1 GHz spectrum in Hong Kong

A report for CSL, HKT, Hutchison and SmarTone

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Executive Summary

In March 2012 OFCA published its first consultation paper[1] on the arrangements to apply to spectrum in the 1.9 to 2.2 GHz band (2.1 GHz spectrum[2]) when licences for existing assignments expire in October 2016. At present there are four mobile operators assigned spectrum in the band – CSL, HKT, Hutchison and SmarTone (3g licensees) and each uses the spectrum to operate a 3g network. A fifth operator China Mobile also offers 3g services, having obtained 3g capacity via MVNO and capacity sharing agreements. All five operators also offer 2g and 4g mobile services. In December 2012 OFCA published its second consultation paper[3] which makes further proposals on the spectrum allocation arrangements and more detailed proposals for the setting of the Spectrum Utilisation Fee (SUF) to apply to 2.1 GHz spectrum.

In its second consultation paper, OFCA assessed the impact of spectrum deprival on 3g service performance and concluded that the *"… reduction in data download speed would be restricted to at most 18% on average during the transitional period"* and that *"… approximately half of the reduction is expected to occur in any case even without any change in frequency assignments"*.[4] OFCA confirmed that there would be a net 9% data transmission speed reduction as a result of spectrum deprival in its news release on 24 July 2013[5].

However, the OFCA assessment implicitly assumes that subscribers are able to move freely between 3g and 4g networks. It fails to take account of the specific degradation on 3g users and ignores the cost impacts on both consumers and operators.

Plum was commissioned to review the proposals in OFCA's first consultation, to provide an independent appraisal of the technical and economic consequences of the arrangements proposed in the second consultation. Plum has now been commissioned to assess the nature and scale of disruption including cost impacts of OFCA's proposal to adopt Option 3 where the 3g operators are deprived of 2x5 MHz of 2.1 GHz spectrum in various combinations.

This paper shows that the degradation in 3g data download speeds could be 27%, three times the 9% estimated by OFCA, and that there will substantial costs to both consumers and the 3g operators as a direct result of adopting Option 3.

> *"... the degradation in 3g download speeds could be 27%, three times the 9% estimated by OFCA, and there will be substantial costs to both consumers and 3g operators as a direct result of adopting Option 3."*

[1] Arrangements for the Frequency Spectrum in the 1.9 – 2.2 GHz Band upon Expiry of the Existing Frequency Assignments for 3g Mobile Services – Consultation Paper – 30 March 2012

[2] Note that in this report the term 2.1 GHz band/spectrum means the radio spectrum 1920 MHz to 1980 MHz and 2110 MHz to 2170 MHz (i.e. 2x60 MHz of spectrum).

[3] See http://www.coms-auth.hk/filemanager/en/share/cp20121228.pdf

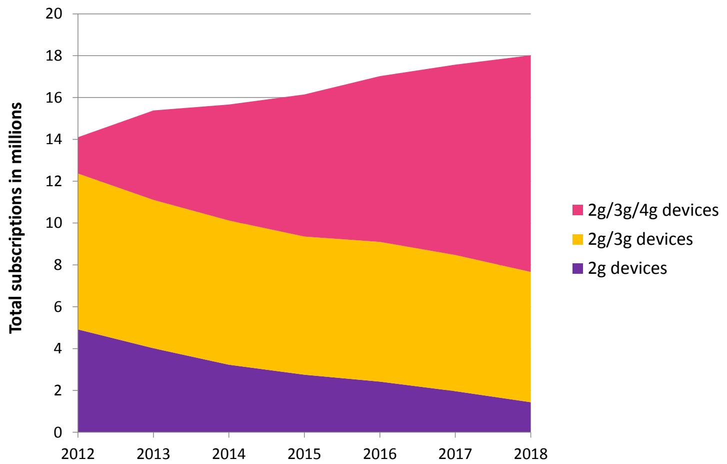
[4] OFCA bases this conclusion on the assumption that the 3g network operators are able to double the 3g network capacity from today's levels and that *"… incumbent 3g operators and/or their customers would be willing to upgrade their network infrastructure and devices …"* to achieve this doubling.

[5] See http://archive.news.gov.hk/en/categories/finance/html/2013/07/20130724_171055.shtml

The 3g spectrum is important for future mobile data support

Over the period to 2018, 3g subscriptions will only experience a slight reduction as shown in Figure 1 and in 2016, when spectrum deprival under Option 3 will take place, around 40% of subscribers would prefer 3g for the provision of mobile data services.

Figure 1: Mobile device capability



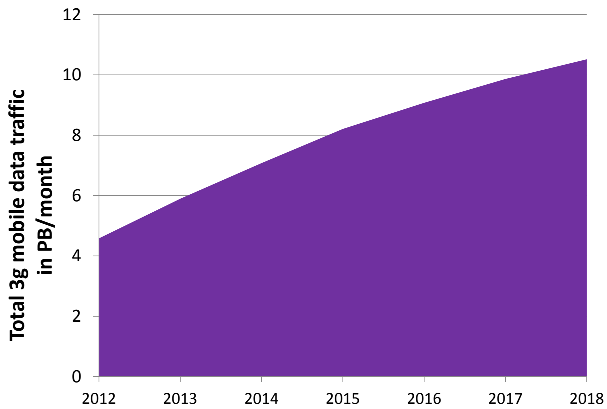
"Although substantial growth is expected for 4g users, the number of users that prefer 3g does not fall significantly in the period up to 2018"

Source: 3g operator data, Plum analysis

Furthermore, mobile data traffic demand in Hong Kong will continue to grow rapidly over this period as shown in Figure 2. Our analysis suggests that the demand for mobile data on 3g will grow substantially:

- by a factor of two in the period to 2016 and
- by a factor of 2.3 by 2018.

Figure 2: 3g system traffic demand



"3g traffic demand will continue to grow; doubling by 2016 and by a factor of 2.3 by 2018"

Source: 3g operator data, Plum analysis

Overall traffic growth including 4g traffic will be even greater and considerable investment in 4g networks will be necessary to accommodate the take-up of 4g services. However even with subscriber migration to 4g, the 3g spectrum will still be the technology of choice of a substantial number of users and an important percentage of the data traffic will still be carried over 3g networks. In addition, 3g will continue to be used as the fallback spectrum/network where 4g coverage does not exist.

We have modelled the impact of spectrum deprival that occurs with OFCA's Option 3 as this is OFCA's preferred option. The modelling took account of operator supplied data and the potential to increase the capacity of 3g networks both by spectral efficiency and increasing sector density (i.e. cell site efficiency):

- The data suggests that there is no practical scope for increasing the spectral efficiency of 3g networks in Hong Kong in the areas where the highest traffic demand exists (i.e. where congestion already exists or will likely exist in period 2016-2018).
- We believe that sector density in these hotspot areas could be marginally increased to enhance the capacity of 3g networks but there are many practical constraints and substantial costs to achieving this[6].

Upgrading the MTR and in-building coverage is another major concern and these bring additional practical and cost constraints. This is especially so in the case of the MTR where the length of time required for planning and implementing changes could be up to 3 years. Building and MTR access has been a long standing problem for operators in Hong Kong.

With a doubling of demand for 3g traffic and only limited ability to increase 3g network capacity in hotspot areas, the 3g operators will need to optimise their networks carefully to support as many 3g users as possible. We found that even without spectrum deprival and the most optimistic capacity assumptions, the future growth in 3g traffic demand cannot be accommodated beyond 2016. A more likely scenario is that overall 3g network capacity grows by around 6% from current levels and that 3g traffic carried is capped at this level from 2014.

"… even without spectrum deprival, the future growth in 3g traffic demand cannot be accommodated beyond 2016."

Deprival of spectrum will severely degrade service performance for 3g users

When 3g operators are deprived of spectrum in October 2016, they will be unable to compensate for the loss of capacity in the most congested areas, having exhausted all means of 3g network capacity enhancement. In addition we consider it highly unlikely that those acquiring the deprived spectrum at auction would utilise the spectrum for the provision of 3g services since they would be unlikely to obtain an adequate return on their investment.

Therefore the maximum user data download speeds will be directly affected by the spectrum loss. On the MTR and at some outdoor locations the loss of 3g capacity may be catastrophic for voice and data services, where the volume of users already threatens to overload the network capacity just with the background signalling traffic of inactive users.

In outdoor areas, we find the capacity loss to be up to 3 times worse than OFCA's estimate with an average 27% loss of capacity at the busiest sites. This figure is derived primarily from the weighted

[6] Including gaining access to suitable rooftops and lower level sites in hotspot areas and the logistics, complexity and time involved in obtaining the necessary permissions to implement these new sites.

average loss of 3g spectrum under deprival across the four operators (which is 24%); however the *mobile data* capacity loss is exacerbated by the need to reserve 14% of the pre-deprival capacity to maintain 3g voice performance.[7]

Where 3g demand is doubling and congestion already exists, a 27% loss of 3g capacity can only be harmful to consumers and result in a substantial decline in service quality. When 3g transmitters are switched off in October 2016, there will be an immediate impact on 3g mobile data services as shown in Table 1. Clearly the impact will be highest on the 3g operators with the least spectrum for 3g services. Consumers will bear the brunt of the service degradation in terms of dropped voice calls, longer download times for video files and failed attempts to access the Internet.

Table 1: Impact of spectrum deprival on the service quality experienced by users

	Impact on service quality of deprival of 2x5 MHz from each 3g operator	
	Subscribers of the 3g operator with greatest reliance on 2.1 GHz spectrum	**Weighted impact on all 3g subscribers (note 1)**
Spectrum holdings usable for 3g	2x15 MHz	2x21.25 MHz (average)
Loss of spectrum	33%	24%
Loss of mobile data capacity	39%	27%
Impact on voice in busy periods	Risk of complete loss of voice communications on the MTR and some outdoor locations	Risk of complete loss of voice communications on the MTR and some outdoor locations
Impact on mobile data in busy periods	39% reduction in data download speed leading to 64% increase in download times in busy periods A typical YouTube video will take 77 seconds longer to download. (note 2)	27% reduction in data download speed leading to 37% increase in download times in busy periods A typical YouTube video will take 44 seconds longer to download. (note 2)
	1 in 4 failure rate in accessing a typical two way video channel	1 in 7 failure rate in accessing a typical two way video channel
	Delays in accessing 1 Mbps streamed video will escalate from 5 seconds to infinity (i.e. service not supportable)	Average delays in accessing 1 Mbps streamed video will escalate from 5 seconds to 7 minutes

Note 1: This is a weighted average impact where all four network 3g operators are deprived of spectrum.
Note 2: Based on a typical YouTube video of 15 MB file size normally taking 2 minutes to download.

As can be seen from the above table, in the worst case, spectrum deprival could result in a 64% increase in download times, more than 6 times worse than implied by OFCA's estimated 9% reduction in data download speed.[8] If 850/900 MHz spectrum is refarmed for 4g prior to spectrum deprival this could be the case for all 3g users.

"… spectrum deprival could result in a 64% increase in download times, more than 6 times worse than implied by OFCA's assessment"

[7] The performance of voice services is very sensitive to capacity reduction. Reduction in the capacity reserved for voice would result in increased call blocking and dropped calls beyond regulatory limits and would not be acceptable to users.

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Furthermore, the degradation shown in Table 1 is not confined to a few isolated instances. The busiest sites are distributed across residential and commercial areas throughout Hong Kong and the impact will be felt at multiple peak times during the day: the commuting peak times, the business busy hours and throughout the evening in residential districts.

Moreover, many visitors to Hong Kong will be reliant on 3g networks for their mobile communications needs and they will experience similar service degradation to that faced by local users. This is contrary to the policy stated by the Commerce and Economic Development Bureau to *"position Hong Kong as the premier digital city and telecommunications hub of Asia"*.[9]

Spectrum deprival will impose costs on both consumers and 3g operators

A comparison of costs and benefits when making a regulatory decision is an important aspect of best practice. In our response to OFCA's 2nd consultation we highlighted the point that OFCA has failed to identify any credible or quantifiable benefits of Option 3.

Conversely, there are substantial costs that will result from Option 3. Consumers will bear the brunt of these costs directly but 3g operators will also need to make unnecessary network investments.

- 3g operators deprived of spectrum will need to spend unnecessarily to upgrade 3g networks prior to 2016 outside of the most congested areas to minimise the impact on consumers. We estimate these costs at HK$ 708 million if all four 3g operators are deprived of spectrum[10]
- Although 3g subscribers cannot be forced to migrate to 4g networks, the degradation in service performance is likely to encourage gradual migration following spectrum deprival. We estimate when deprival occurs that 23% of 3g mobile subscribers (9% of total subscriptions) will need to migrate to 4g to reduce traffic and return performance to pre-deprival levels. This would affect 1.5 million subscriptions from 2016, and 3g consumers would be forced to prematurely spend approximately HK$ 5.4 billion for new 4g smartphones[11].
- There would also be a need to bring forward some 4g network investment to accommodate the migrating 3g subscribers. This results in relatively modest additional costs of HK$ 145 m.[12]

> *"… the total costs resulting from spectrum deprival could be as high as HK$ 6.3 bn, the vast majority of which will be borne directly by consumers."*

Therefore the total costs resulting from spectrum deprival could be as high as HK$6.3 billion, the vast majority of which will be borne directly by consumers.

[8] OFCA's estimated 9% reduction in download speed is equivalent to a 10% increase in download times (i.e. = 1/[1-0.09]-1)

[9] See CEDB mission statement at http://www.cedb.gov.hk/ctb/eng/about/mission.htm

[10] These include the costs of additional sites and sectorisation where it is possible to implement. The estimate is a net present value in 2016 and includes all capital and operational expenditure for the period 2016 to 2018.

[11] An average cost of HK$ 3,500 based on smartphone prices ranging from HK$3,000 to HK$5,000 in 2016, with an allowance for the trade-in value of 3g handsets.

[12] The estimate is a net present value in 2016 and includes capital and operational expenditure. It is much lower than the equivalent 3G investment cost because 4g has an inherently lower cost per unit of traffic and the capex has been amortised over the entire equipment lifetime with only the period from 2016 to 2020 being considered incremental to the non-deprival case.

Option 3 is a poor decision for Hong Kong

In summary, our analysis of the impact of spectrum deprival under Option 3 is as shown in Table 2.

Table 2: Comparison of impacts associated with Option 1 and Option 3

	Option 1 (3g operator retains 2.1 GHz spectrum)	**Option 3** (3g operator is deprived of 2x5 MHz)
Impacts on consumers	3g service performance is maintained in high traffic areas	Risk of complete loss of voice communications on the MTR and some outdoor locations Service performance is severely degraded in high traffic areas Download times increase by 37% (typ.) and potentially 64% Failure rates for high data rate services will become worse. Typically 1 in 7 attempts and potentially 1 in 4 Delays in commencing video streaming session could render the service unusable
	No additional costs imposed on consumers	1.5 million subscriptions are potentially affected and consumers would need to spend up to HK$ 5.4 billion on new smartphones.
Impacts on 3g operators	3g operators are able to optimise investments to ensure continuing service quality for 3g users	3g operators will incur additional costs of up to HK$ 708 million in 3g network upgrades to counter the adverse impact of spectrum deprival.
	4g operators are able to optimise investments in 4g technology	4g operators will incur additional costs of up to HK$ 145 million in additional capacity to provide for dissatisfied 3g subscribers migrating to 4g.

We find that the degradation of service performance described in Table 2 will occur in all outcomes where any of the 3g operators are deprived of spectrum, although the number of affected subscribers will vary. The costs incurred by consumers and operators are substantial (HK$ 3.1 billion to HK$ 6.3 billion) for the range of most probable outcomes of an auction under Option 3.

In the absence of any quantified benefits for the Hong Kong economy, a decision to adopt Option 3 can only have a net cost to Hong Kong, and this cost could be as high as HK$ 6.3 billion. Consumers will bear the brunt of these costs directly as well as suffering substantial degradation of 3g service quality. The additional network costs are also likely to be borne by users in the long run. When coupled with OFCA's proposed Spectrum Utilisation Fees (SUF), the total costs of OFCA's proposal ultimately borne by consumers could total HK$ 15.5 billion[13].

"… Option 3 is manifestly against the interests of mobile users by degrading the ability of users to communicate whilst directly increasing their costs."

In short, re-licensing based on Option 3 is manifestly against the interests of mobile users by degrading the ability of users to communicate whilst directly increasing their costs. Option 3 is also contrary to the stated policy of the Communications Authority and inconsistent with global best practices.

On this basis, Option 1 should be adopted for re-licensing the 2.1 GHz band.

[13] Based on a SUF of HK$77m / MHz for 80 MHz of spectrum retained by the current 3g operators plus a reserve price of HK$77m / MHz for the 40 MHz of spectrum to be re-auctioned under Option 3.

1 Introduction

OFCA is considering options for relicensing of the 2.1 GHz band[14] and has consulted on three options for the relicensing process. The options are:

- Option 1 - to allow rights of first refusal for all current spectrum holdings in the 2.1 GHz band.
- Option 2 - to auction all spectrum in the 2.1 GHz band (in its second consultation OFCA stated that the SCED[15] had come to the view that there were overriding public policy reasons to deviate from the full-fledged market approach of 3g spectrum reassignments proposed in Option 2 and hence this option would not be considered further).
- Option 3 - to allow rights of first refusal for 2x10 MHz of currently held spectrum and to auction the remaining spectrum. This is the option proposed by the SCED and the CA in the second consultation paper.

In its second consultation paper, OFCA assessed the impact of spectrum deprival on 3g service performance and concluded that the *"… reduction in data download speed would be restricted to at most 18% on average during the transitional period"* and that *"… approximately half of the reduction is expected to occur in any case even without any change in frequency assignments"*.[16] OFCA confirmed that there would be a net 9% data transmission speed reduction as a result of spectrum deprival in its news release on 24 July 2013**[17]**.

However, the OFCA assessment implicitly assumes that subscribers are able to move freely between 3g and 4g networks. It fails to take account of the specific degradation on 3g users and ignores the cost impacts on both consumers and operators.

In the LegCo hearing on 27 March 2013, OFCA commented that it had commissioned a study to assess the disruption that may arise from its preferred option, Option 3. OFCA stated that it will use the output from the study in its recommendation for the most appropriate option to adopt.

The incumbent 2.1 GHz operators have commissioned this study from Plum with two objectives:

- To quantify the potential cost impact of spectrum deprival from the incumbent 2.1 GHz operators
- To provide an independent view by developing this study in parallel with the work being undertaken by OFCA in assessing the potential quality and consumer impacts associated with Option 3.

We understand that a great deal of operator specific data has been provided in support of the OFCA study. This Plum study is based as far as possible on the same dataset; however it does include additional data that was specifically requested by Plum to fully quantify impacts.

This report assesses the nature and scale of disruptions including cost impacts. The structure of the remainder of the report is as follows:

- Section 2 describes the methodology used to determine impacts

[14] OFCA has carried out two consultations – March 2012 and December 2012

[15] Secretary for Commerce and Economic Development

[16] OFCA bases this conclusion on the assumption that the 3g network operators are able to double the 3g network capacity from today's levels and that *"… incumbent 3g operators and/or their customers would be willing to upgrade their network infrastructure and devices …"* to achieve this doubling.

[17] See http://archive.news.gov.hk/en/categories/finance/html/2013/07/20130724_171055.shtml

- Section 3 presents the key technology and market assumptions
- Section 4 assesses the impact of spectrum deprival on 3g networks and the services provided
- Section 5 considers the impacts on operators that gain 3g spectrum
- Section 6 presents the results of the study and assesses the overall economic impacts of Option 3 versus a base case of Option 1.
- The appendices provide supporting material.

2 Methodology

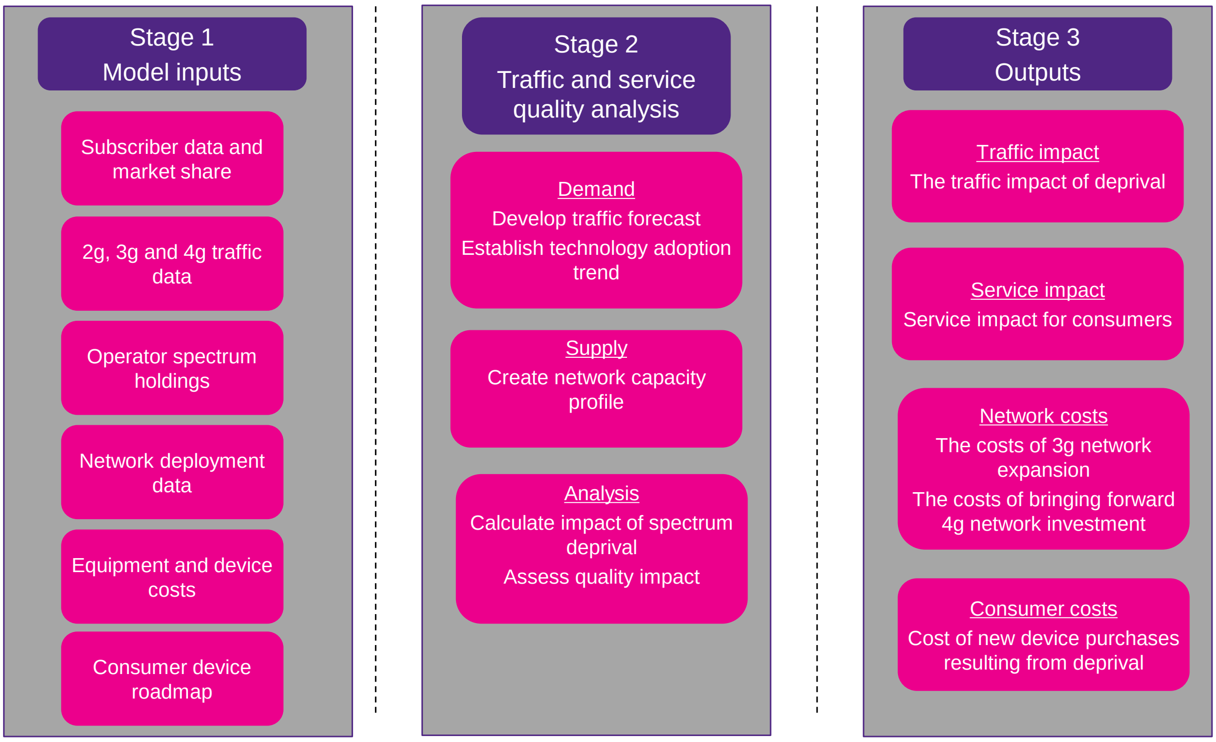
2.1 Overview

The impact assessment in this report takes account of service performance impacts and the potential costs of adopting Option 3 for re-licensing 2.1 GHz spectrum. The service performance, consumer costs and network deployment costs are compared for:

- The baseline scenario based on Option 1, where 2.1 GHz spectrum is re-licensed to the incumbent 3g operators, and
- A set of auction outcome scenarios based on Option 3, where each incumbent 3g operator is deprived of 2x5 MHz of 3g spectrum.

To quantify the impact of these scenarios Plum developed a model structured as shown in Figure 2-1. The model comprises a demand side model that maps technology take-up in Hong Kong and forecasts subscribers and traffic demand for 2g, 3g and 4g services; and a supply side model that takes account of the spectrum available for each operator, network deployment and capacity.

Figure 2-1: Model structure for analysis of service performance and costs



By comparing the traffic forecast for 3g with the maximum capacity of the 3g network for the baseline scenario we were able to quantify the 3g service performance under Option 1 (i.e. where no 2.1 GHz spectrum is deprived). Varying the spectrum supply for each operator under the potential auction outcome scenarios allowed us to quantify the degradation in service quality that results from Option 3, and the costs incurred by consumers and network operators to enable 3g subscribers to obtain acceptable service quality in the longer term.

2.2 Demand side modelling

The demand side of the model required inputs on:

- Technology roadmap – the rate of take-up of 3g and 4g devices – in general we assume that subscribers that have 4g capable devices will use 4g networks rather than 3g
- Traffic forecast – to establish a traffic forecast we compared expectations of traffic growth provided by the 3g operators with an industry forecast for the Asia Pacific region derived from Cisco and a forecast published by OFCA in its consultation document.

2.3 Supply side modelling

The supply side of the model involves the development of a model to represent the capacity that can be supported in actual Hong Kong networks given the spectrum available.

The impacts of spectrum deprival are evaluated by changing the spectrum supply assumptions in the model.

The supply side modelling results in three main outputs:

- The service quality degradation experienced by a loss of capacity per site for each operator in the busiest areas
- The need to upgrade network capacity outside the busiest areas to compensate for spectrum deprival
- The subscribers and traffic that must migrate to 4g networks in the longer term to restore 3g service quality to an acceptable level.

2.4 Modelling of cost impacts

Cost impacts are considered in terms of:

- Consumer impacts – the costs to 3g subscribers that must purchase a 4g smartphone to avoid the service quality degradation
- Network operator impacts – the costs to operators to upgrade 3g network capacity to compensate for the loss of 3g spectrum and 4g network capacity to accommodate the additional traffic contributed by 3g subscribers forced to migrate to 4g.

2.5 Scenarios to be modelled

We have used Option 1 where the 2.1 GHz band is re-licensed to the existing operators as a baseline case for analysis. Each of the potential auction outcome scenarios is then compared to the baseline case to quantify the consequences of a decision based on Option 3. It is crucial that the impacts of all potential outcomes are considered in the analysis.

The impact of 1, 2, 3 and 4 of the 3g operators being deprived of 2x5 MHz of spectrum must be evaluated, and for each of these cases, the impacts of the deprived spectrum being acquired in the auction by other 3g operators, a mobile operator without 3g spectrum or a market entrant must also be considered.

The severity of impact in each case depends on the degree to which operators are able to upgrade their 3g networks and accommodate future growth in 3g traffic. For the purposes of the model, we have assumed that each operator will upgrade its network to embody best practice capacity provision that is practically achievable. However, we recognise that in practice it will be very difficult for all operators to adopt best practice capacity provision due to physical and technical constraints. We have further assumed that 3g traffic will be distributed across the 3g operators networks in proportion to the capacity provided under the baseline scenario. This approach avoids the bias that would be introduced by making specific assumptions about the network quality of individual operators and the traffic they may carry in future.

For each scenario we consider the service quality impacts of spectrum deprival where:

- The capacity of each 3g network deprived of a 2x5 MHz carrier is reduced
- The 3g subscribers of affected networks face reduced quality of data services in the busiest areas
- Voice and data users of affected networks will face particular difficulty accessing communications on the MTR.

The service quality impacts would occur immediately in October 2016 when equipment using the deprived spectrum must be switched off. We have assumed that 3g operators will invest in 3g network upgrades outside of the busiest areas to compensate for spectrum deprival, although there is a risk that operators will be reluctant to invest in new 3g equipment in the period prior to 2016.

With time, we would expect the most severely affected subscribers to be forced to migrate to 4g networks to obtain acceptable service quality. These subscribers are in addition to those that would migrate to 4g without spectrum deprival, and they will have no choice but to incur the cost of new 4g capable handsets and all the network operators will have to incur extra cost to accommodate the additional 4g traffic.

All of these service degradations and costs will be a direct result of a decision to adopt Option 3 and could therefore be avoided by adopting Option 1.

2.6 Assessment of economic impacts on Hong Kong

The service degradation caused by spectrum deprival will create consumer harm and it is a cost to Hong Kong. In addition there will be a negative impact for visitors who roam onto the 3g networks in Hong Kong. These visitors will experience the same degradation as users with Hong Kong registered mobiles.

The economic effects of deprival will be comprised of three elements:

- The additional costs faced by 3g network operators in upgrading their networks where this is possible outside of the busiest areas

- The additional costs faced by consumers for purchase of 4g devices
- The additional costs faced by network operators for bringing forward investment in 4g networks.

The three cost categories above are real costs resulting from the decision to adopt Option 3. We distinguish between these real costs and the costs and benefits that are simply the transfer of value from one operator to another. Such transfers have no net impact in a proper economic analysis.

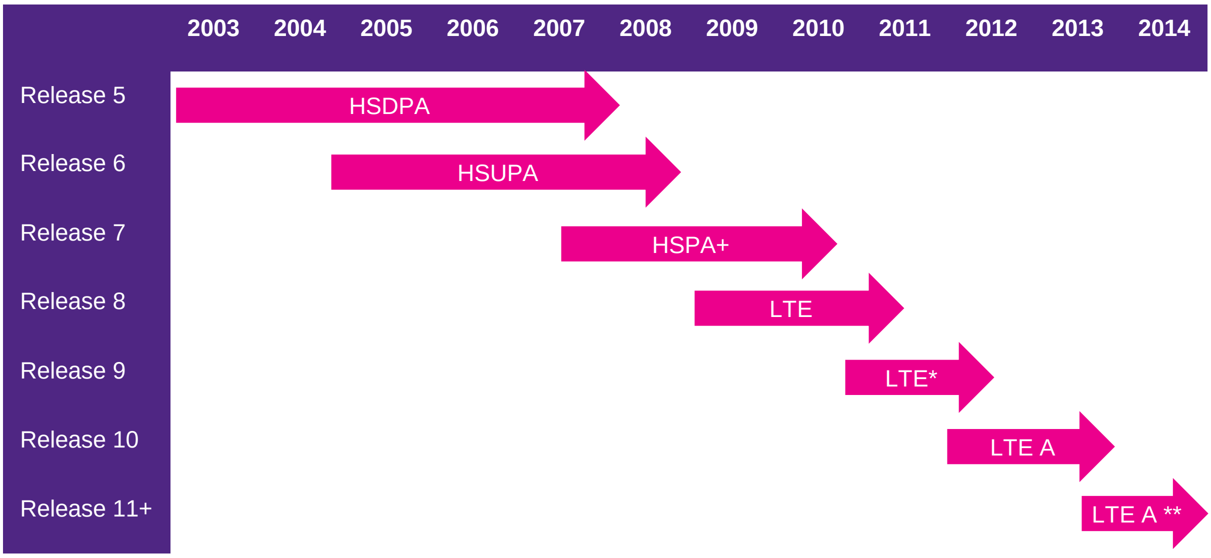
Similarly the amounts paid in spectrum auction receipts and Spectrum Utilisation Fees (SUF) have no net impact on the Hong Kong economy; however they do raise costs for operators and consumers.

3 The Hong Kong market and technology roadmap

The implementation of new mobile technology is an incremental process dependent on the availability of both network equipment (e.g. mobile base stations) and devices (e.g. smartphones, tablets, dongles, etc). The combination of network and devices for a particular technology is often referred to as its ecosystem. In practice there is a considerable period of co-existence of technologies as seen today in Hong Kong where GSM, 3g and 4g networks are all in operation.

Much of the functionality of mobile networks is standardised by 3gpp[18] and an example of the timing of new technology releases from 3gpp is shown in Figure 3-1. The work of 3gpp strongly influences the design of network equipment and devices.

Figure 3-1: 3gpp technology standards releases



*Enhancements to LTE
**Enhancements to LTE-A

Source: 3gpp, Plum

3.1 Mobile device evolution

Mobile device evolution is a function of network evolution and the capability of processors, memory, displays, batteries and other aspects of devices. While some consumers have the latest devices that work with 3g and 4g there are many consumers using devices not capable of accessing more advanced networks. OFCA's market data[19] gives an indication of this split with 9.38 million subscriptions out of 16.39 million customers being 3g/4g (57%) and the remainder (43%) being GSM

[18] http://www.3gpp.org/Releases 3gpp produces technical specifications that are subsequently incorporated in to technical standards for mobile systems. It has a wide membership comprised of equipment vendors, standards organisations and others

[19] Key statistics for telecommunications in Hong Kong for December 2012: 03/03/2013 – note these numbers include activated prepay SIMs that may not be active on networks resulting in a lower number of active devices

only. These figures are informative. They indicate that even after many years since 3g services were first introduced, there are many GSM users who have not yet migrated to 3g, let alone 4g. On this basis, it seems unlikely that 3g users will migrate rapidly to 4g services.

Use of new technology increases over time as the population of new devices grows. However there is still a significant requirement to support devices using older technology: the decline in use of older devices lags behind the introduction of new devices by several years.

Consumer migration to new devices generally occurs in several phases as described below:

- Early adopters (usually within the first year of introduction)
- Mass adoption (this period could extend over a period of several years)
- Late adopters.

There may also be a segment of the market that will not adopt new devices for a number of reasons including that they simply see no need to change / cannot afford to change from their existing device.

The implications of subscriber migration are described in more detail below.

3.2 Subscriber migration

Over the past decade we have seen a migration of traffic from GSM to 3g as users have bought handsets capable of both GSM and 3g operation. We expect this process to continue and for the number of GSM-only subscribers in Hong Kong to reduce to less than 8% of total subscribers by 2018.

Today there are a substantial number of 3g handsets in operation and 3g traffic is still growing and in parallel we foresee migration and growth in 4g device capability. Consumer incentives for migration to 4g devices vary:

- For some the purchase of a high end smartphone may mean that they are able to utilise 4g services in bands used for LTE in Hong Kong
- For others, the faster services will be desirable with the increasing use of data hungry smartphone applications.

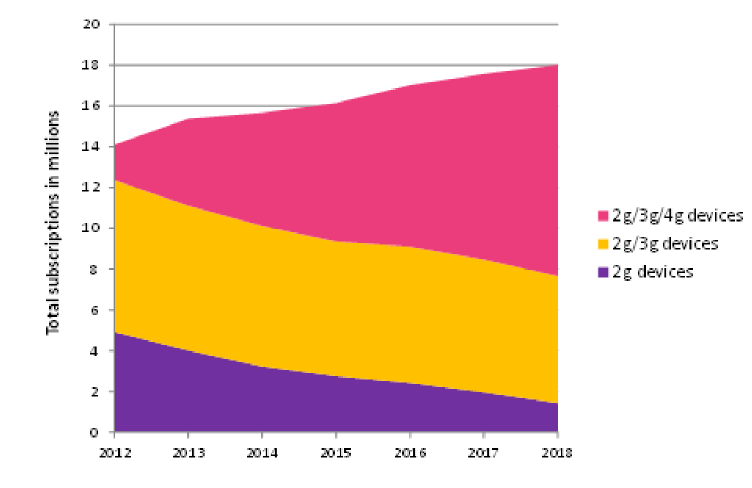
OFCA's statistics on mobile take-up and usage show that the speed of migration from 2g to 3g took 7 years to reach 50% penetration of total active subscriptions.[20] We have assumed a similar speed of take-up of 4g services with approximately 50% penetration being achieved in 2016. We have forecasted subscriber numbers by device capability in the Hong Kong market as shown in Figure 3-2.[21] An important feature of this forecast is that although substantial growth is expected for 4g users, the number of 3g users does not fall significantly in the period up to 2018 and still accounts for around 40% of total subscriptions in 2016. This is a result of continuing popularity of low end smartphones (without LTE support) and a vibrant second hand handset market that gives access to 3g handsets at relatively low cost for GSM users seeking to upgrade. This means that there will still be a substantial

[20] See http://www.ofca.gov.hk/filemanager/ofca/en/content_108/wireless_en.pdf

[21] This forecast is based on data on subscriber numbers and MVNOs contributed by the 3g operators and reconciled with OFCA subscription data. Note that the OFCA data does not specifically exclude SIMs that have been activated but are no longer used. Consequently the reconciliation had to take account of some operators' view of "active" subscribers which was based on the number of devices attached to the network at a particular moment in time.

number of 3g subscribers that need to be supported beyond October 2016 when spectrum deprival would occur under Option 3.

Figure 3-2: Mobile device capability



"Although substantial growth is expected for 4g users, the number of users that prefer 3g does not fall significantly in the period up to 2018"

Sources: 3g operator data, OFCA, Plum analysis

Of course there is some uncertainty around the future rate of take-up of mobile technologies. We have used the historical rate of take-up of 3g services in Hong Kong as a guide since this is the best indicator for the behaviour of the Hong Kong market. Take-up of 4g may turn out to be faster or slower in reality although there is no evidence to suggest this. Also the take-up of cheap secondhand 3g phones may accelerate migration of 2g subscribers to 3g – thereby increasing the population of users reliant on 3g networks.

Our forecast demonstrates the continuing importance of 3g for a large proportion of subscribers in Hong Kong to 2016 and beyond and reflects a reasonable view of the future Hong Kong market. It would not be appropriate to base regulatory decisions on a speculative view of the future market (e.g. one that assumed a speedier migration to 4g device capability). To do so would not be conservative, and would ignore the needs and preferences of consumers.

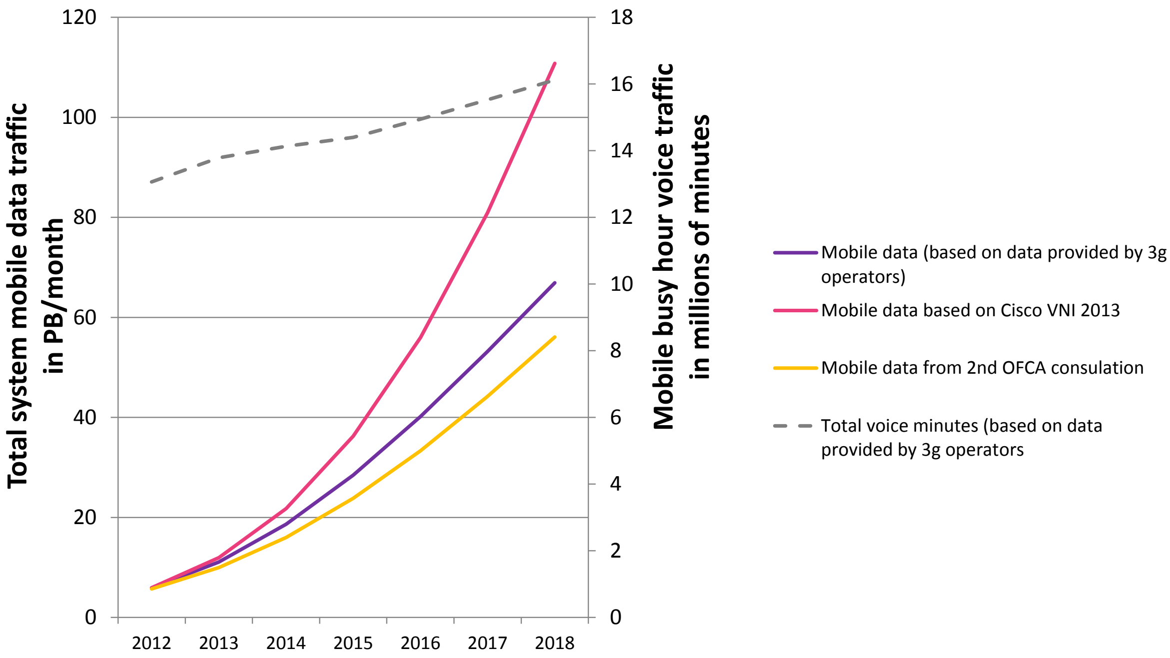
3.3 Traffic forecast

The 3g operators provided the study with their forecasts for GSM, 3g and 4g voice and mobile data traffic demand over the medium term to 2016. This was used to estimate the total mobile voice and data traffic demand to 2018 as shown in Figure 3-3. In the figure the data forecast is also compared to OFCA's forecast from the 2nd consultation paper on licensing the 2.1 GHz band[22] and a traffic forecast

[22] "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, OFCA, 28 December 2012

for Hong Kong derived from OFCA reported traffic data[23] and Cisco forecasts for growth in similar Asia Pacific markets.[24]

Figure 3-3: Mobile voice and data traffic forecast



Sources: 3g operators' data, Cisco VNI, OFCA, Plum analysis

As can be seen from the traffic forecasts, our predicted mobile traffic based on 3g operator data is approximately 19% higher in 2018 than that projected by OFCA in its 2nd consultation and around 60% lower than that implied by the Cisco VNI 2013 forecast. For this study we have adopted the mobile data forecast based on 3g operator supplied data, but we have considered below the robustness of our 3g traffic forecast in the context of the Cisco-based and OFCA forecasts. Although our forecast differs from the Cisco-based and OFCA forecasts we believe that the differences reflect the uncertainty in the future take-up of 4g services, rather than the traffic demand for 3g services. More modest growth is projected for voice traffic at around 23% over the period 2012 to 2018.

The 3g operators predict that more than half of Hong Kong's subscribers will still be using 2g and 3g technology in 2016 and more than 42% in 2018. We consider this a reasonable assumption given the historic migration from GSM to 3g. We expect that subscribers with the highest data usage will migrate to 4g first and that more than half of data traffic will be carried by 4g from around 2014. However we expect 3g traffic demand will continue to grow; doubling by 2016 and factor of 2.3 by 2018 as shown in

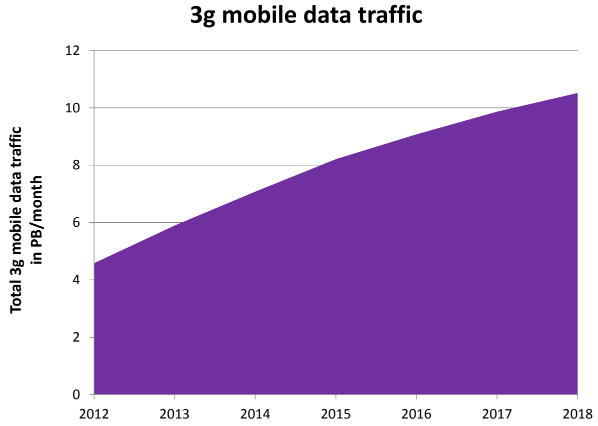
[23] Mobile traffic statistics are collated by OFCA and reported on its website. See http://www.ofca.gov.hk/filemanager/ofca/en/content_108/wireless_en.pdf

[24] The forecast is based on year on year growth estimates for Japan and Korea in the Cisco Visual Networking Index Global Mobile Data Traffic Forecast Update 2012 -2017. http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf

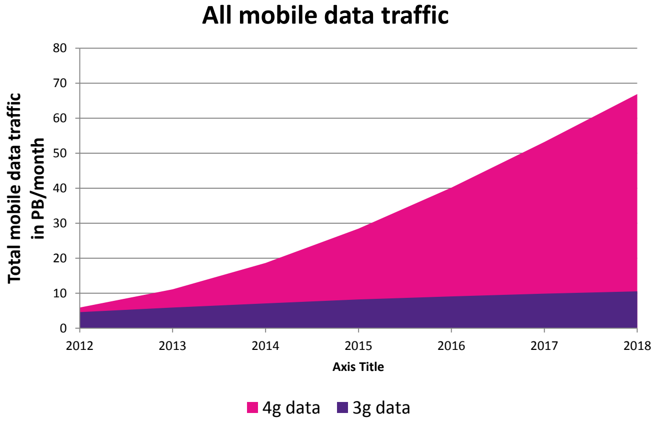
Figure 3-4. Traffic demand for 3g is expected to continue to form a substantial part of total traffic volume (23% of total mobile data in 2016 and 16% in 2018).

From this it is clear that although a great deal of traffic demand will be served by 4g from 2014, a substantial and still growing amount of traffic demand will still be served by 3g over this period and around 40% of Hong Kong mobile subscribers are expected to still rely on 3g services in 2016.

Figure 3-4: Total system traffic demand by technology in Hong Kong



"3g traffic demand will continue to grow; doubling by 2016 and grows by a factor of 2.3 by 2018"



"Despite 4g traffic growth, around 40% of Hong Kong subscribers will still prefer 3g in 2016"

Source: 3g operator data, Plum analysis

Figure 3-4 represents traffic *demand* and as such it is the level of traffic for which mobile operators will seek to dimension their 3g and 4g networks. However, the traffic *carried* by the networks will depend upon physical limitations of the networks in the busiest areas of Hong Kong and the amount of spectrum available for delivery of services.

3.4 Responding to growth in 3g traffic demand

The potential for 3g operators to upgrade their networks in the busiest areas in response to increases in 3g traffic demand has been assessed in Appendix A. It is the ability to support traffic in these busiest areas that dictates how much of the 3g traffic demand may be accommodated.

The analysis in Appendix A finds that there are capacity constraints in different environments:

- In the outdoor environment – the capacity is limited by the practical ability to achieve greater site density and sectorisation in highly congested areas such as Central, Wan Chai, Causeway Bay and Mongkok. If all operators were able to achieve the same peak site density and sectorisation then this would suggest that transceiver density could be increased by around 27%, however we doubt that this is achievable in practice or that it would indeed result in a net improvement in capacity. This is because:
  - As sites become closer together direct line of sight interference tends to degrade spectrum efficiency resulting in little net increase in capacity
  - Landlords are reluctant to grant access to rooftop sites due to concerns about radiation and visual impact
  - Planning restrictions prevent the implementation of additional sites at street level
  - Operators are already achieving a best practice level of spectrum efficiency.

  As a result of the uncertainty regarding these factors we have considered two scenarios for 3g network development:

  i. A **baseline capacity scenario** where capacity is assumed to increase by 6% (corresponding to the implementation of 2x5 MHz of 900 MHz spectrum not currently used for 3g), and
  ii. An **optimistic capacity scenario** where capacity is assumed to increase by 35% (a combination of 6% increase in spectrum availability and benefits from the potential increase in site/sector density; i.e. 1.06 x 1.27 = 1.35).

  This second scenario is considered only to test the sensitivity of our conclusions to the traffic supported by 3g networks in the future.

- On the MTR system:
  - The capacity of the concourse systems is theoretically upgradable but in practice could take 3 years to implement planned work. It appears unlikely that such work would be completed in time to cater for increases in 3g traffic demand.
  - The capacity of the tunnel systems is more severely constrained and is only likely to be increased in response to a new spectrum release affecting the spectrum holdings of the majority of operators.
  - The 3g uplink performance in tunnels is a particular concern given the high volume of users. Excessive noise in the uplink can cause complete failure of mobile communications, a problem that would be exacerbated by further increases in 3g traffic or the deprival of a 2x5 MHz carrier. This problem is also observed outside of the tunnels where the MTR runs through outdoor hotspots.

- All 4g handsets currently use the 3g network for voice communications which will exacerbate the uplink noise problem. Although Voice over LTE (VoLTE) standards should be implemented in the 4g networks by 2016, the additional uplink noise contributed by 4g terminals on the MTR will not be reduced until new VoLTE capable handsets become a significant proportion of total 4g handsets. However, the non-VoLTE capable handsets will remain on 3g networks even then, through the second hand market.

Accordingly, this means that there would unlikely be any changes made to the tunnel systems if it is simply to accommodate one particular operator's acquisition of 3g spectrum. Furthermore, 3g voice and mobile data service availability is highly sensitive to the number of both 3g and 4g users in the tunnels; the occasional outage even without spectrum deprival shows that service performance is highly reliant on all the 2.1 GHz spectrum being available for provision of 3g services.

- Indoor systems - in general provision of indoor coverage faces similar problems to the MTR (e.g. planning, being able to gain access to do the work), although the problems are not as severe.

We also considered the potential for new and complementary technologies such as Multiple Input Multiple Output (MIMO) antennas, femto cells, Hetnets and public WiFi to augment the capacity of 3g networks. However, in all cases they either required users to change their mobile devices or they fail to provide coverage that is an effective substitute for mobile services.

To avoid the assessment being reliant on the individual operator's market performance (which is uncertain) we have further assumed that each operator's traffic is in proportion to the capacity provided by the network (as enabled by its spectrum holdings).[25]

[25] As 2g subscribers continue to migrate to 3g services, we would expect that 3g network performance will be a factor that influences their choice of network. Since 3g networks will be limited in capacity by their 3g spectrum holdings, it is reasonable to assume that the new 3g subscribers will be distributed in 2016 according to the maximum capacity 3g operators are able to implement.

4 Impact of spectrum deprival on 3g networks

Assuming that each operator exercises its right of first refusal under Option 3, then it is possible for one, two, three or four operators to be deprived of 2x5 MHz of spectrum as a result of the auction. The severity of impact depends on the spectrum holdings and traffic carried by each operator; therefore we have taken account of 3g operator data in our assessment.

4.1 Impacts on the performance of 3g services

Outdoor 3g networks

Depriving 3g operators of a single 2x5 MHz carrier has a major impact on the capacity that can be supported. Generally the 3g operators will need to use all their spectrum resources at every site to maximise the throughput of their networks. This means that, when a 3g operator is deprived of 2x5 MHz of 2.1 GHz spectrum, they will lose between 23% and 39% of 3g network capacity for mobile data, depending upon how much 850/900 MHz spectrum they currently have. The impact of spectrum deprival on mobile data capacity is greater than the proportion of spectrum holdings because some capacity is effectively reserved for voice (i.e. we would expect voice traffic to be given priority over data traffic).[26]

On average 3g networks would lose 27%[27] of mobile data capacity upon spectrum deprival in 2016 as illustrated in Figure 4-1 in the baseline capacity scenario and Figure 4-2 in the optimistic capacity scenario. In particular, it should be noted that the 27% loss in mobile data capacity is not sensitive to the degree of capacity growth that can be achieved in 3g networks. This is because all practical techniques to increase 3g capacity are expected to be exhausted prior to 2016 even under the most optimistic circumstances.

We find that the *absolute* loss of capacity under the optimistic capacity scenario is greater than for the baseline scenario therefore the number of consumers affected and the costs associated with remedial actions for the optimistic capacity scenario will be higher. Since we do not consider the optimistic capacity scenario to be realistic and to include it would tend to exaggerate the total costs of Option 3, we have not included it in our subsequent analysis as to do so may overstate the adverse impacts.

[26] The proportion of 3g spectrum lost would be between 20% and 33% depending on an operator’s 850/900 MHz spectrum holdings. However, operators would need to maintain voice performance following spectrum deprival and voice services consume around 14% of 3g capacity. Therefore the impact on mobile data capacity is exacerbated to between 23% and 39%.

[27] An average across the four 3g networks weighted by 3g traffic carried. This assumes that all 850/900 MHz spectrum continues to be used for 3g services.

Figure 4-1: Impact of spectrum deprival in baseline capacity scenario

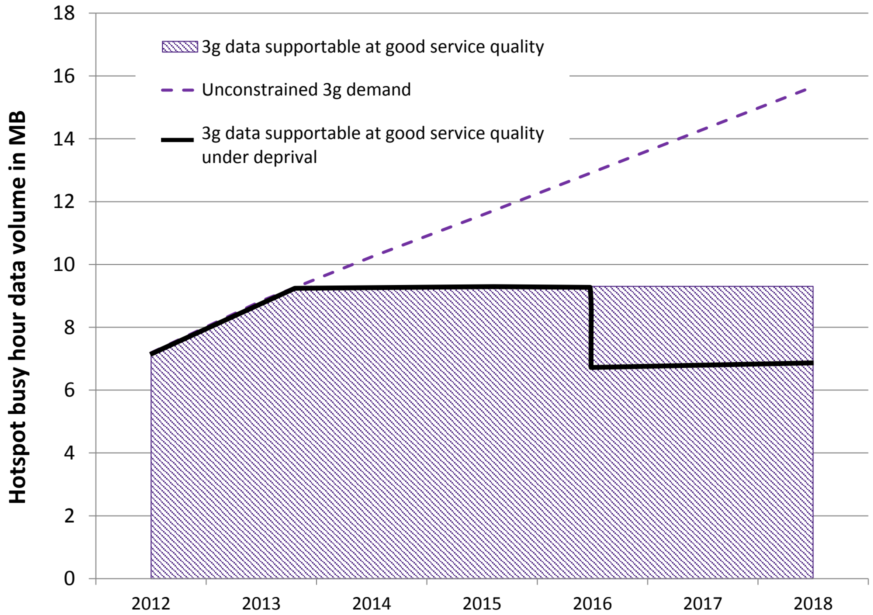
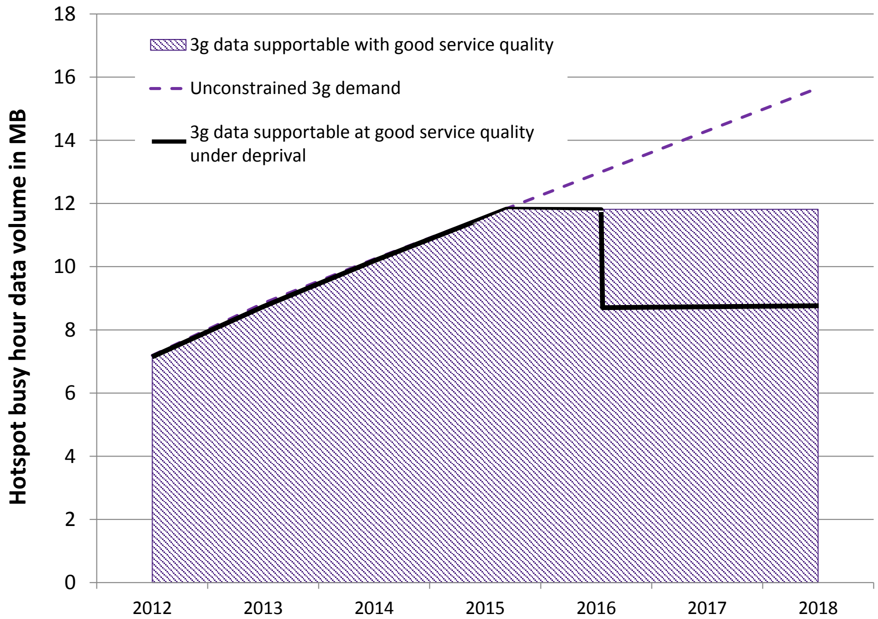


Figure 4-2: Impact of spectrum deprival in the optimistic capacity scenario



It is good practice for operators to dimension their network to provide a specified level of service to data customers. When data loading is such that insufficient capacity remains in a cell, new access attempts will fail until cell loading reduces sufficiently to accommodate the new access. Spectrum deprival and the resulting reduction of capacity will therefore reduce the number of users / amount of data throughput the cell can support at a good quality of service. A 27% loss in capacity resulting from spectrum deprival will have a profound impact on users and create consumer harm from the time transmitters are deactivated in October 2016. Table 4-1 shows examples of the harm caused.

Table 4-1: Impact of a 27% capacity loss on 3g busy hour data service quality

Aspect of service	Impact of 2x5 MHz deprival on a single operator
Failure rate for accessing a 1 Mbps service (as an effective real-time service) (e.g. two way video channel)	In a typical cell using 4 transceivers of 2x5 MHz, 8.2 simultaneous connections can be supported at this rate or an average of 4.5 users for a blocking rate of 5%. Reducing the capacity by 27% will mean that the number of available connections reduces to 6 and the blocking rate will rise threefold to 15% for the same offered traffic. Nearly 1 in 7 access attempts at this data rate will fail.
Delay experienced by user attempting to access a 1 Mbps service (Streamed video service)	As above a typical cell using 4 transceivers of 2x5 MHz will support 8.2 simultaneous channels at this rate. Assuming the average download time is 30 seconds (3.75 MB of data volume) and a 5 second access delay can be tolerated then 712 streams could be handled in one hour. Reducing the capacity by 27% and supporting the same number of streams, means that the average delay will escalate. In this example the delay would escalate to from 5 seconds to more than 7 minutes.
Average download times	To maintain adequate grade of service, download speeds will have to be reduced by at least 27%. This means that download times will increase by 37%. A typical YouTube video of 15 MB file size normally taking 2 minutes to download will take 44 seconds longer.

Most of the above degradation characteristics are based on impairment of the downlink. In situations where uplink noise at the base station receiver impairs uplink performance, both uplink and downlink performance will degrade further due to the breakdown of signalling protocols. We have not specifically modelled uplink performance in this assessment, however given that the problem has already been observed in MTR tunnels and some outdoor areas, it is clear that 3g voice and mobile service integrity is highly reliant on all the 2.1 GHz spectrum being available for 3g services.

Where operators migrate spectrum currently used for 3g services to 4g deployment (i.e. 900 MHz) these impacts would be exacerbated since the deprived spectrum would form a greater proportion of the spectrum deployed for 3g in 2016. In this report we have assumed that operators would maximise the use of their current holdings for 3g service delivery in response to spectrum deprival. However, it should be noted that depriving 3g operators of 2.1 GHz spectrum would constrain operators with 900 MHz spectrum to bring forward the deployment of additional 4g capacity in a flexible manner.

Spectrum deprival on the MTR tunnel systems

Reducing the spectrum holdings for any of the 3g operators will reduce the capacity provided to that operator's subscribers on the MTR. Again typical capacity losses will be around 27% and this will have a similar impact to the outdoor 3g networks case.

As discussed in Appendix A uplink noise issues are likely to be a serious problem on the MTR network given the potentially large number of 3g and 4g devices in one sector and the proximity of devices to the leaky feeder in the tunnel connected to the base station receiver. With the loss of 27% of capacity, the 3g devices (and 4g devices reliant on the 3g network for voice) will be concentrated on the remaining 3g carriers. With this effective 37%[28] increase of users on each carrier, complete outages for voice and mobile data services, which occur occasionally even now, will become more frequent during busy commuting periods. The reliance of 4g users on the 3g network for their voice communications means that many 4g users would also be affected. Note also that this is likely to occur in outdoor locations where the MTR runs through hotspot areas.

Spectrum deprival on MTR concourse areas and indoor systems

In the concourse areas of the MTR and for other indoor systems, it is technically possible for the number of 3g cells to be increased to compensate for the loss in 3g capacity, although this would take time. While an auction of 3g spectrum in 2014 could theoretically leave sufficient time to upgrade indoor systems in advance of spectrum deprival, the following aspects must be taken into account before this can be assumed to happen:

- MTR concourse and some other indoor systems are shared between the mobile operators. Changes to the Point of Insertion (PoI)[29] are typically funded by the individual operator(s) requesting the changes. New installations would need the cooperation of all the mobile operators.
- The process of making changes to PoI in conjunction with the MTR is time consuming and can take up to three years to complete. MTR upgrades would be unlikely to happen in time for spectrum deprival.
- Incentives for the 3g network operators to fund changes to PoI to increase capacity for a short period are weak. Customers may migrate to 4g services before operators obtain a return on the investment.

Given the high cost and investment risk faced by 3g operators that are deprived of 2.1 GHz spectrum, we do not consider it reasonable to expect that they would compensate for the loss in capacity by funding the implementation of more indoor systems.

Therefore similar performance degradation is likely in MTR concourse and indoor areas as will be experienced outdoors.

[28] The effective increase per carrier is calculated from 0.27 / (1-0.27) = 0.37.

[29] A Point of Insertion (PoI) is a defined point at which a network operator's equipment is connected to a distributed antenna system in the MTR concourse or tunnels. It comprises a finely engineered system of radio frequency filters and combiners that ensure that both uplink and downlink links in the coverage area are at appropriate power levels for each operator connected to the PoI.

4.2 Cost impacts of spectrum deprival

Cost of 3g network expansion outside of the busiest areas

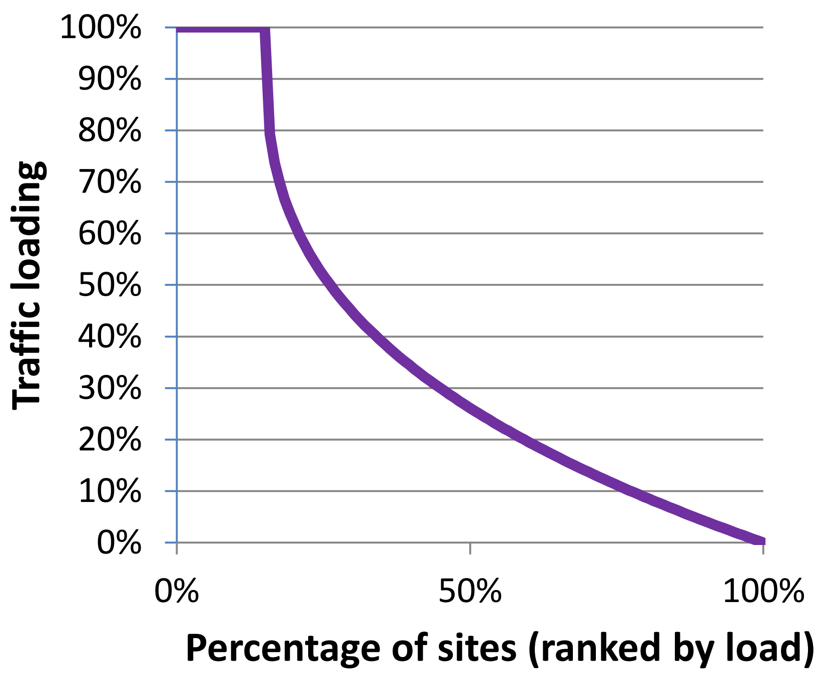
The impact of losing 2x5 MHz will be to decrease the effective capacity on each site in the network and to compensate for this loss, 3g network operators will need to increase the level of sectorisation on some sites (where this is possible) and split some other sites.

Therefore we can consider the 3g network in three parts:

- Highly loaded sites that would need to be split into smaller sites
- Moderately loaded sites for which further sectorisation would compensate for loss of 2x5 MHz
- Lightly loaded sites for which loss of 2x5 MHz has no impact.

We have estimated the distribution of traffic in 2016 based on the current distribution of 3g traffic for the baseline capacity scenario, which is shown in Figure 4-3.

Figure 4-3: Estimated distribution of 3g traffic load in 2016



Source: 3g operator data, Plum analysis

To consider the impact of a 27% loss of capacity, we estimated the additional sites and sectorisation required for the baseline scenario. The costs associated with these network adjustments are detailed in Table 4-2 and show that the total costs of 3g network upgrades required before spectrum deprival in 2016 would be HK$ 708 million if all four 3g operators were deprived of spectrum.

Table 4-2: Costs of 3g network upgrade for the baseline scenario

Number of pre-deprival sites	8109
Additional sites required due to deprival	487 (6% of sites)
Cost per additional site	HK$ 1,338k
Total cost of additional sites (note 1)	HK$ 652m
Number of sites requiring additional sectorisation	487 (6% of sites)
Cost per additional sectorisation	HK$ 116k
Total cost of additional sectorisation per site	HK$ 56m
Total 3g costs of deprival	**HK$ 708m**

Note 1: Includes the total costs of site establishment and site equipment for a typical site supporting 4 sectors with 2x20 MHz of spectrum deployed in each sector. The estimate is a net present value in 2016 and includes all capital and operational expenditure for a two year period discounted at a rate of 10%. Site equipment costs are based on typical deployment costs used by Plum for other mobile markets.

Note 2: This is the estimated capital and cost of adding a fourth sector onto a three-sector site. The equipment and maintenance costs are calculated using the same methodology as the site costs.

Cost of further migration of subscribers to 4g

It is clear that 3g subscribers and visitors to Hong Kong would experience a substantial degradation of service quality as a result of spectrum deprival. In response to this we would expect an increase in migration to 4g networks by those that are most sensitive to poor service quality. With time this migration could reduce traffic levels sufficiently to allow 3g service performance to return to normal levels. However, the forced migration of 3g subscribers to 4g has significant costs to Hong Kong.

These costs are associated with:

- The need for migrating consumers to buy 4g smartphones that they would not have bought otherwise, and
- The need for operators to bring forward investment in 4g networks to accommodate the additional traffic generated on their networks sooner than would otherwise be the case.

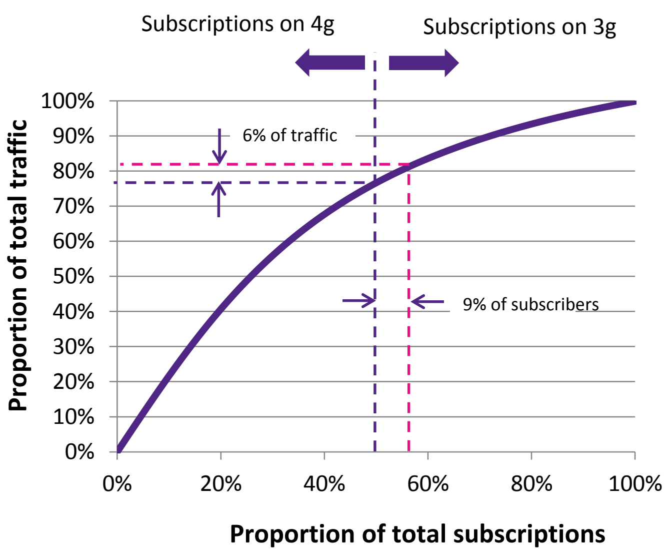
Device costs

We have established that around 27% of 3g network capacity would be lost if all four 3g operators were deprived of 2x5 MHz of 2.1 GHz spectrum. This represents around 6% of total network capacity in 2016. To translate this traffic into a number of users we considered the traffic demand contributed by users ranked by their volume of usage. In 2016 we expect this distribution to have the shape shown in Figure 4-4. The analysis suggests that 9% of mobile subscribers (23% of 3g subscribers) will need to migrate from 3g to 4g to reduce traffic on 3g networks by 27% and return performance to non-deprival levels. In 2016 this means that an additional 1.5 million subscriptions could potentially be required to convert to 4g at an approximate cost of HK$ 5.4 bn[30]. As consumers churn devices on a

[30] An average cost of HK$ 3,500 based on smartphone prices ranging from HK$3,000 to HK$5,000 in 2016, with an allowance for the trade-in value of 3g handsets.

relatively rapid basis, say on average every two years, we have not discounted this cost. Although one might expect that some of these subscriptions would have migrated in the following years in the non-deprival case, there will still remain underlying growth in 3g traffic per subscriber and a requirement in each following year for traffic to be 27% lower than the non-deprival case. Therefore the net additional migration in each year due to spectrum deprival will be the number of subscribers that corresponds to a 27% reduction in traffic.

Figure 4-4: Estimated distribution of traffic by subscribers in 2016



Source: 3g operator data, Plum analysis

4g network costs

To understand the potential 4g network deployment costs, we have considered the costs of additional LTE transceivers and site establishment that would need to be implemented earlier than planned by network operators under the assumption that the extra traffic (i.e. the traffic that would have been carried on 3g) can be accommodated efficiently.

Our analysis suggests that an additional investment of HK$175m will be required in the period 2016 to 2020. In 2016 terms this investment has a net present value of HK$145m.[31]

[31] This network investment is estimated from the incremental costs of the radio access network assuming that the network capacity is provided efficiently. It includes site establishment, network equipment and operational costs such as maintenance, backhaul and site rental. All capital expenditure was amortised over the lifetime of the equipment and a discount rate of 10% was used for the analysis. The estimate is the net present value of 4 years of the annualised costs.

5 Impact on operators that gain 3g spectrum

Where any operator gains additional 2.1 GHz spectrum, this can only be at the expense of at least one 3g operator being deprived of spectrum. Therefore the key consideration is whether or not the additional spectrum gained by another operator can compensate for the adverse impacts of spectrum deprival.

In theory, the acquiring operator may deploy 3g technology such that there is no net change in overall 3g capacity. However, the acquiring operator may choose to not use the 2.1 GHz spectrum for 3g network deployment and instead retain the spectrum for later deployment of 4g technology. In this case there will be a net loss of 3g capacity and the negative impacts on consumers will remain.

Even in the case where the spectrum is used for 3g deployment:

- Consumers will still suffer the service degradation until the time that they decide to move to an alternative operator
- Changing the configuration of the MTR will not be possible within the timescale and would be at a high cost to the acquiring operator
- The acquiring operator would incur unnecessary cost in deploying the additional 3g network capacity.

For an acquiring operator in this position, whether they be a 3g operator, incumbent operator without 3g spectrum or a new entrant, there is little commercial benefit to gain by deploying additional 3g network resources. Its use would only be for a transitional period and therefore unlikely to provide a return on investment. A 3g operator would more logically invest in LTE network deployment and/or handset subsidy to encourage migration to 4g.

6 Results

6.1 Impacts on service quality

Over the period to 2018 mobile data traffic in Hong Kong will continue to grow rapidly. Our analysis suggests that overall data growth will be by a factor of 16. Much of this data traffic growth will be on 4g networks post 2014. However 3g traffic will grow significantly:

- by a factor of two in the period to 2016 and
- by a factor of 2.3 by 2018

This growth will be driven by a significant continuing population of 3g devices and migration from GSM to 3g as GSM usage declines. However operators will have only limited ability to increase 3g network capacity. In the outdoor environment capacity growth will be limited to between 6% and 35% from today's levels, in the indoor environment it is unlikely to grow significantly and on the MTR practical installation issues prevent upgrades in a timely manner. From 2016 3g network capacity will be constrained and subsequent growth in 3g traffic demand will be forced to gradually migrate to 4g networks as users most sensitive to service quality find 4g more attractive.

Consumer harm

With spectrum deprival in October 2016, the affected operators will need to immediately deactivate 3g network capacity using the deprived spectrum. The resulting reduction in capacity will severely degrade the mobile data service quality for all their 3g customers. In busy hotspots, the degree of degradation depends on what proportion the deprived spectrum is of their total 3g spectrum holdings. On the MTR the increased numbers of 3g and 4g users per carrier is likely to have a profound impact resulting in the complete loss of voice and mobile data communications on the affected 3g network. These are summarised in following table.

Table 6-1: Summary of service performance impacts in the busy hours

	Impact on service quality of deprival of 2x5 MHz from each 3g operator		
	Subscribers of the 3g operator with greatest reliance on 2.1 GHz spectrum	**Subscribers of the 3g operator with lowest reliance on 2.1 GHz spectrum**	**Weighted impact on all 3g subscribers (note 1)**
Spectrum holdings usable for 3g	2x15 MHz	2x25 MHz	2x21.25 MHz (average)
Loss of spectrum	33%	20%	24%
Loss of mobile data capacity	39%	23%	27%
Impact on voice in busy periods	Risk of complete loss of voice communications on the MTR and some outdoor locations	Risk of complete loss of voice communications on the MTR and some outdoor locations	Risk of complete loss of voice communications on the MTR and some outdoor locations

	Impact on service quality of deprival of 2x5 MHz from each 3g operator		
Impact on mobile data in busy periods	39% reduction in data download speed leading to 64% increase in download times A typical YouTube video will take 77 seconds longer to download. (note 2)	23% reduction in data download speed leading to 30% increase in download times A typical YouTube video will take 36 seconds longer to download. (note 2)	27% reduction in data download speed leading to 37% increase in download times A typical YouTube video will take 44 seconds longer to download. (note 2)
	1 in 4 failure rate in accessing a typical two way video channel (see note 3)	1 in 7 failure rate in accessing a typical two way video channel (see note 3)	1 in 7 failure rate in accessing a typical two way video channel (see note 3)
	Average delays in accessing 1 Mbps streamed video will escalate from 5 seconds to infinity (i.e. service not supportable) (see note 4)	Average delays in accessing 1 Mbps streamed video will escalate from 5 seconds to 7 minutes (see notes 4 and 5)	Average delays in accessing 1 Mbps streamed video will escalate from 5 seconds to 7 minutes (see note 4)

Note 1: This is a weighted average impact where all four network 3g operators are deprived of spectrum

Note 2: Based on a typical YouTube video of 15 MB file size normally taking 2 minutes to download.

Note 3: Calculation of the blocking rate using the Erlang B assessment methodology for non-queued systems

Note 4: Calculation of the blocking rate using the Erlang C assessment methodology for queued systems

Note 5: The delay for the subscribers of the 3g operator with lowest reliance on 2.1 GHz spectrum, is the same as for the weighted impact on all 3g subscribers because the number of channels after a 23% or 27% reduction rounds to the same integer value.

These impacts will not be mitigated by further investment in 3g by those that acquire spectrum:

- At least initially demand and supply will not match if another operator deploys new 3g capacity – there will be a requirement for users to churn to access the new capacity
- New investments based on acquiring spectrum from 2016 will be based on consideration of all the technology choices available and there is a high probability that operators will invest in 2.1 GHz LTE rather than advanced 3g if the ecosystem exists.

To assume that operators will invest in 3g technology from 2016 onwards would require operators to make investment decisions to alleviate the consumer harm arising from a bad regulatory decision, which it is clearly not in their commercial interests to do.

6.2 Impact on visitors to Hong Kong

For the next few years OFCA cannot assume that all visitors will have handsets and roaming agreements with their host operator that are capable of operating on 4G. Many visitors are likely to use 3g services for both voice and data roaming.

The quality of experience for a visitor roaming onto a 3g network in Hong Kong will be similar to that experienced by a mobile user registered in Hong Kong. In general most visitors do not choose the network they roam onto and it is possible that during their visit to Hong Kong a mobile will roam onto several of the 3g networks. Hence roamers will experience the quality of several networks during their stay. As a result even if a single operator is deprived of spectrum, visitors to Hong Kong will at some stage experience the same service degradation that is experienced by Hong Kong subscribers. Implementation of Option 3 with its deprival of 3g spectrum will clearly have a negative impact for the provision of roaming services, which is contrary to the policy stated by the Commerce and Economic Development Bureau to *"position Hong Kong as the premier digital city and telecommunications hub of Asia"*.[32].

6.3 Cost impacts

Spectrum deprival would result in immediate service quality degradation for subscribers in October 2016. We would expect 3g subscribers to tolerate the reduced service quality for a period of time due to decision inertia or the constraints of their mobile service contracts.[33] We estimate the additional costs to subscribers from changing their handsets as a result of deprival to be as shown in Table 6-2. The total costs faced by consumers could be as high as HK$ 5.4 bn if all four 3g operators are deprived of 2.1 GHz spectrum.

Table 6-2: Costs of deprival incurred by consumers directly for new smartphones

	Costs of deprival of 2x5 MHz of 2.1 GHz spectrum from each 3g operator		
	Subscribers of the 3g operator with greatest reliance on 2.1 GHz spectrum	Subscribers of the 3g operator with lowest reliance on 2.1 GHz spectrum	Weighted impact on all 3g subscribers of a typical operator*
Spectrum holdings usable for 3g	2x15 MHz	2x25 MHz	2x21.25 MHz (average)
Share of total 3g spectrum	18%	29%	25%
Consumer costs (at 2016 prices)	HK$ 0.97 billion	HK$ 1.57 billion	HK$ 1.35 billion
* This is a weighted average impact where all four network 3g operators are deprived of spectrum			

The cost impacts on network deployment (3g and 4g) are summarised in Table 6-3. The total costs faced by network operators could be as high as HK$ 853 m for both 3g and 4g network expansion if all four 3g operators are deprived of 2.1 GHz spectrum.

[32] See CEDB mission statement at http://www.cedb.gov.hk/ctb/eng/about/mission.htm

[33] This point is acknowledged by OFCA in its 2nd consultation, page 12 paragraph 23. Typical service contracts range from 12 to 24 months.

Table 6-3: Cost of additional 3g and 4g investments required due to deprival

	Costs of deprival of 2x5 MHz of 2.1 GHz spectrum from each 3g operator		
	Subscribers of the 3g operator with greatest reliance on 2.1 GHz spectrum	**Subscribers of the 3g operator with lowest reliance on 2.1 GHz spectrum**	**Weighted impact on all 3g subscribers***
Spectrum holdings usable for 3g	2x15 MHz	2x25 MHz	2x21.25 MHz (average)
Share of total 3g spectrum	18%	29%	25%
Additional 3g investment costs	HK$ 127 million	HK$ 205 million	HK$ 177 million
Additional 4g investment costs	HK$ 26 million	HK$ 42 million	HK$ 36 million
Total additional network costs	HK$ 153 million	HK$ 247 million	HK$ 213 million
* This is a weighted average impact where all four network 3g operators are deprived of spectrum			

6.4 Consideration of scenarios

We have assessed the impacts for each of the outcome scenarios shown in Table 6-4. Each of these scenarios is compared with Option 1 (where all spectrum is re-licensed to the current holders) which forms the counterfactual scenario.

As observed in Section 5, acquirers of 2.1 GHz spectrum that are not current 3g spectrum holders are unlikely to use the 2.1 GHz spectrum for the provision of 3g services. Similarly, current 3g spectrum holders that might increase their holdings of 2.1 GHz spectrum as a result of the auction would be unlikely to use the spectrum to deploy additional 3g network equipment. This means that all scenarios that differ only by the types of operator that acquire a net increase in 2.1 GHz spectrum, result in the same impact on 3g services.

Furthermore, the service degradation in 2016 described in this report has the same impact on individual consumers under all scenarios where one or more 3g operators are deprived of 2.1 GHz spectrum. These scenarios differ only in the quantity of mobile subscriptions that suffer impaired performance.

For simplicity, we have illustrated the impacts in Table 6-4 based on each operator that is deprived of 2.1 GHz having the average amount of 3g spectrum – called a 'typical 3g operator' for the purposes of this report. In reality there will be some variability of impact depending upon the precise spectrum holdings of each operator. In general, for a 3g operator currently having less 2.1 GHz of spectrum, the cost impacts associated with individual operator may be 30% lower, but the service degradation more severe. Conversely, spectrum deprival for a 3g operator with above average current 3g spectrum holdings will incur higher costs and less severe service degradation. Therefore we consider that computing the impact for each scenario assuming each operator so deprived of spectrum is a 'typical 3g operator', is broadly representative of the severity of each scenario.

Table 6-4: Outcome scenarios associated with Option 3 (assuming that each 3g operator exercises right of first refusal)

Scenario	Number of incumbent operators with 2.1 GHz spectrum					Number of operators without 2.1 GHz spectrum (incumbent or new entrants)				Total costs incurred by consumers and mobile operators due to spectrum deprival	Number of 3g subscriptions affected by service degradation
	2x10 MHz	2x15 MHz	2x20 MHz	2x25 MHz	2x30 MHz	2x5 MHz	2x10 MHz	2x15 MHz	2x20 MHz		
1		4									
2	1	3				1				HK$ 1.6 billion	0.38 million
3	1	2	1							HK$ 1.6 billion	0.38 million
4	2	2					1			HK$ 3.1 billion	0.75 million
5	2	2				2				HK$ 3.1 billion	0.75 million
6	2	1	1			1				HK$ 3.1 billion	0.75 million
7	2	1		1						HK$ 3.1 billion	0.75 million
8	2	0	2							HK$ 3.1 billion	0.75 million
9	3	1						1		HK$ 4.7 billion	1.13 million
10	3	1				1	1			HK$ 4.7 billion	1.13 million
11	3	1				3				HK$ 4.7 billion	1.13 million
12	3		1				1			HK$ 4.7 billion	1.13 million
13	3		1			2				HK$ 4.7 billion	1.13 million
14	3			1		1				HK$ 4.7 billion	1.13 million
15	3				1					HK$ 4.7 billion	1.13 million
16	4								1	HK$ 6.3 billion	1.5 million
17	4					1		1		HK$ 6.3 billion	1.5 million
18	4						2			HK$ 6.3 billion	1.5 million
19	4					2	1			HK$ 6.3 billion	1.5 million
20	4					4				HK$ 6.3 billion	1.5 million

It should be noted that even though Scenario 1 has identical spectrum holdings to the counterfactual, there would still be incremental costs associated with the uncertainty during the period leading up to the auction outcome being known and the costs of implementing the auction by OFCA and for all industry players to participate in the auction. There will also be costs associated with reconfiguration of spectrum deployments given that the spectrum gained may be different frequency ranges to that prior to the auction.

For all the remaining scenarios, some 2.1 GHz spectrum is deprived from incumbent 3g operators. We find that the impacts on consumers are additive in that the number of consumers affected increases with the number of operators that lose spectrum. Although, there is some potential for 3g operators to cooperate with increasing the number of indoor systems if all four are deprived of spectrum, there are not strong commercial incentives to do this and full agreement is unlikely. The service degradation for 3g users outdoors and on the MTR cannot be mitigated except by further migration of users away from 3g networks.

Although spectrum that is deprived will be gained either by another 3g operator, an operator currently without 2.1 GHz spectrum or a new entrant, we consider it unlikely that the spectrum will be used for supplementing 3g capacity. It is more likely that the spectrum will be retained for later deployment of LTE services.

We have observed that in most auctions worldwide for spectrum that can be used for 4g, there has been a preference for spectrum blocks of at least 2x10 MHz of spectrum to allow LTE networks to maintain efficiency and support a genuine increase in service capability over 3g systems. Indeed some regulatory authorities package the spectrum into 2x10 MHz blocks prior to the auction to ensure that this occurs in the outcome.

Therefore we believe that a range of probable outcomes of an auction under Option 3 is that 2, 3 or 4 of the 3g mobile operators would be deprived of spectrum. This means that 0.75 to 1.5 million subscriptions would suffer the service degradation described in Section 6.4 and the total unnecessary costs imposed by Option 3 would range from HK$ 3.1 bn to HK$ 6.3 bn.

6.5 Overall economic impacts on Hong Kong

A robust decision process for 2.1 GHz re-licensing should be based on a fully quantified cost and benefits analysis. We have not identified any credible or quantifiable benefits associated with Option 3 relative to Option 1.

There are three main sources of quantifiable costs arising from a decision to re-licence based on Option 3:

- Consumer costs in the form of device purchases
- Operator costs to expand the 3g networks outside the busiest areas
- Operator costs to expand the 4g networks to accommodate prematurely migrating 3g subscribers.

By far the greatest of these is the harm done to consumers through costs arising from the burden of purchasing new smartphones earlier than they would have otherwise. We estimate that 9% of subscriptions (i.e. 1.5 million) will be forced to migrate at a cost of HK$ 5.4 billion. Also, while it is not possible to directly cost the negative impact on those roaming into Hong Kong as a result of deprival, there will be an additional cost resulting from a poorer roaming service for visitors to Hong Kong.

It should be noted that any mobile operator that gains value through acquiring 2.1 GHz spectrum will do so at the expense of those deprived of spectrum. These are considered to be transfers within the economy and should not be included in a proper cost benefit analysis. Similarly revenues paid to the government in the auction are transfers that result in no net benefit for the Hong Kong economy.

In the absence of any quantified benefits for the Hong Kong economy, a decision to adopt Option 3 can only have a net cost to Hong Kong, and this cost could be as high as HK$ 6.3 billion. Consumers will bear the brunt of these costs directly as well as suffering substantial degradation of 3g service quality. The additional network costs are also likely to be borne by users in the long run. When coupled with OFCA's proposed Spectrum Utilisation Fees (SUF), the total costs of OFCA's proposal ultimately borne by consumers could total HK$ 15.5 billion[34].

In short, re-licensing based on Option 3 is manifestly against the interests of mobile users by degrading the ability of users to communicate whilst directly increasing their costs. Option 3 is also contrary to the stated policy of the Communications Authority and inconsistent with global best practices.

On this basis, it is Plum's recommendation that OFCA's Option 1 should be adopted for re-licensing the 2.1 GHz band.

[34] Based on a SUF of HK$77m / MHz for 80 MHz of spectrum retained by the current 3g operators plus a reserve price of HK$77m / MHz for the 40 MHz of spectrum to be re-auctioned under Option 3.

Appendix A: Assessment of potential 3g network capacity

This appendix considers the potential for 3g operators to upgrade their networks in the busiest areas in response to increases in 3g traffic demand. It describes the areas having the greatest concentration of traffic in Hong Kong (hotspot areas) and considers capacity provision in:

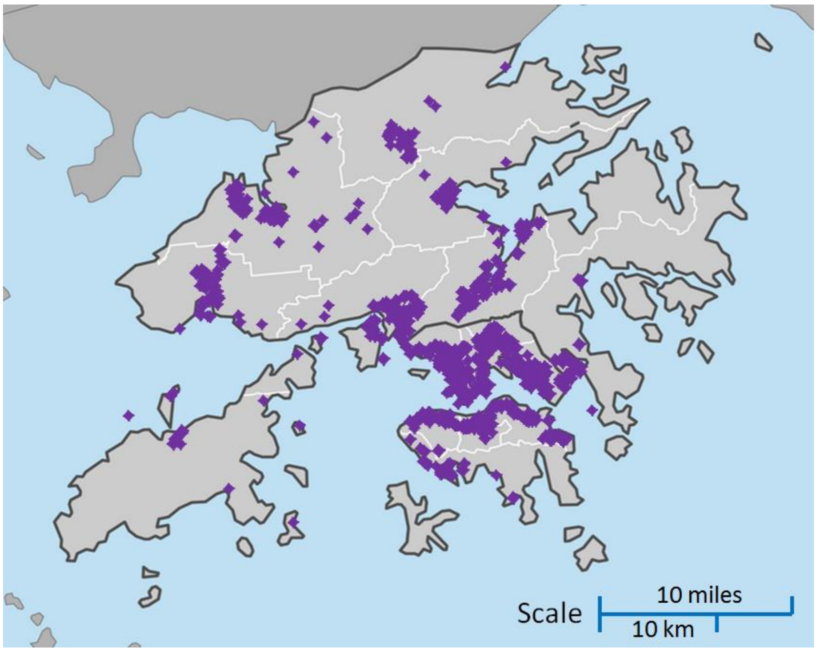
- Outdoor environments
- MTR tunnels
- MTR concourse areas and indoor systems

This appendix also considers the potential for other technologies to complement the capacity of 3g networks.

A.1 Modelling "hotspot" traffic

To assess the impact of spectrum deprival we have modelled the network performance in the busiest part of the mobile operators' networks - hotspot areas. These hotspot areas are defined as the 15% of busiest sites (which carry approximately 40% of the total network traffic in the system busy hour). The majority of these sites are in the dense residential and commercial districts of Hong Kong Island and Kowloon, however there are a substantial number of hot spot sites distributed across Hong Kong as shown in Figure A-1.

Figure A-1: Approximate location of hotspot sites across Hong Kong

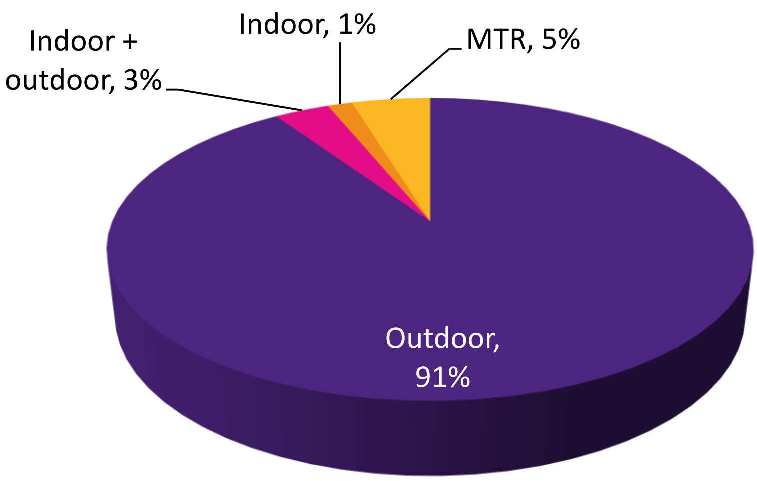


Source: 3g operators' data

From Figure A-1 it is clear that the majority of Hong Kong subscribers will at some stage experience the performance limitations experienced at these hotspot sites. Although we have considered performance across all the hotspot areas it should be recognised that the traffic distribution is not homogenous across the hotspot areas. Spectrum requirements are dictated by the ability of the network operators to serve the areas having the highest traffic density such as Central, Causeway Bay, Wan Chai and Mongkok as well as key interchange stations on the MTR.

The great majority of these locations are outdoor sites however there are a significant number of indoor sites and MTR locations as shown in Figure A-2. Although MTR hot spot sites represent only 5% of hot spots many of these sites, especially the interchange stations, are located in the busiest parts of Hong Kong and have a high throughput of people particularly during peak commuting periods.

Figure A-2: Breakdown of hotspots by type of site



Source: 3g operators' data

A.2 Maximum 3g network capacity outdoors

To understand the impact of spectrum deprival, we have modelled the maximum capacity achievable with each 3G network based on its spectrum resources. The enhancements to future capacity can be considered in terms of:

- Spectrum availability and efficiency
- Site density.

Each of these is considered in turn.

Spectrum availability and efficiency

Operators have different spectrum resources available for 3g network deployment as detailed in Table A-1 and this affects their approach to network deployment.

Table A-1: Spectrum usable for 3G services

Spectrum band[35]	CSL	HKT	Hutchison	SmarTone
850 MHz				2x5 MHz
900 MHz	2x5 MHz		2x10 MHz	2x5 MHz
2.1 GHz	2x15 MHz	2x15 MHz	2x15 MHz	2x15 MHz
Total	*2x20 MHz*	*2x15 MHz*	*2x25 MHz*	*2x25 MHz*
Source: 3g operators				

In general, all of these spectrum resources are used at each site in hotspot areas. There is one exception where a 900 MHz carrier is still being used for GSM services and could potentially be utilised for 3g. This would represent a 6% increase in overall 3g capacity.

Although the spectrum detailed above is usable for 3g, operators may refarm spectrum from these bands to 4g prior to 2016, especially the 900 MHz band which is anticipated to form part of the LTE device ecosystem and has potential for deep in-building penetration. This would tend to reduce capacity available for 3g services and exacerbate the impact of spectrum deprival. In our analysis we have assumed that operators maximise 3g capacity in response to 3g traffic demand and maintain 850, 900 and 2100 MHz resources for 3g service delivery through to 2018.

Our analysis uses the operator making the most efficient use of the 3g spectrum they have deployed as the benchmark for all operators. We have not calculated a theoretical system capacity using spectral efficiency numbers as there is a great deal of variation in the downlink spectral efficiency actually achievable in different environments with different technologies.

- This is especially so when 3g cells are located in close proximity to one another where line of site or near line of site inter cell interference can reduce spectral efficiency
- Achieving the highest spectral efficiency relies on consumers owning handsets that support all of the advanced features necessary for this level of performance. In practice this is unlikely to occur with 3g handsets where, for example, many MIMO features are not implemented.

Appendix B provides an overview of the range of spectral efficiency likely to be achievable with different technologies and implementations. The evidence suggests that a downlink spectral efficiency of 0.41bps/Hz/cell might be the best 3g performance that is achievable in the outdoor high traffic density areas of Hong Kong. This finding is consistent with the feedback we received from talking to the 3g operators. Given that network deployments (layout and equipment) are broadly similar across the 3g operators in the densest traffic areas of Hong Kong we have used a downlink spectrum efficiency of 0.41bps/Hz/cell in our modelling of capacity of the operators' networks.

Site density and sectorisation

From our discussions with the incumbent 3g network operators, we are advised that the outdoor networks deployed in hotspot areas are close to or at the limit of network capacity that it is practical to achieve. Almost all the available suitable rooftop sites have been implemented in these high density

[35] This table excludes the 2x7.5 MHz spectrum in the 825 MHz to 877.5 MHz range assigned to HKT

areas and once site spacing becomes less than around 100 metres the interference environment is such that additional sites generate little incremental capacity[36].

The 3g operators provided us with data on numbers of sites in hotspot areas, site density in key congested areas and the number of sectors and transceivers deployed in hotspots[37]. There is a trade-off to be considered between site spacing and the number of sectors it is possible to implement at each site as the distance between sites reduces. In general, the operators that have greater site spacing in hot spot areas have been able to implement more sectors per site. Those with sites that are closer together have fewer sectors per site. This suggests that there is a practical limit for the sector density that can be achieved and that the ability of 3g operators to further increase 3g network capacity is extremely limited in high density areas.

Increasing outdoor site/sector density further could partly be addressed by implementing additional smaller cells at street level. Although we observed a few such cell sites in Hong Kong typically installed on advertising hoardings, changes to planning regulations now make the installation of such sites more difficult than in the past. [38] [39]

The issues for deployment of such sites include:

- The logistics and complexity of the approval process with OFCA, the Transport Department, Highways Department and Lands Department all potentially being involved in the approval of an application
- The restrictions on mounting antennas on buildings and other surfaces, where the antennas and their mountings are not permitted to protrude beyond the building line. This effectively prohibits the mounting of antennas on the sides of buildings and for those mounted at roof or podium level it means that antennas cannot extend beyond the edge of the building unless operators seek approval from the Building Department (which significantly increases the time required for approval).

If OFCA is able to improve access to rooftops and streamline planning/approval procedures then it could marginally assist the 3g operators in increasing the capacity of their 3g networks prior to 2016. However, there are still technical and practical limitations in installing additional antennas in already congested cell sites that render it difficult to increase capacity in such areas. For instance, one of the major difficulties faced by operators is the reluctance of landlords to allow base stations to be installed on their premises because of worries regarding potential radiation hazards and their visual impact. Nevertheless, for the purposes of our model, we have also considered the potential for further 3g network capacity increase under the assumption that each 3g operator is able to achieve the same sector density as the 3g operator currently having the highest sector density.

Figure A-3 shows how we calculated the potential increase in capacity resulting from increasing sector density for the 3g operators in Hong Kong. We calculated the highest sector density achievable in high

[36] At this site spacing the risk of line of sight or near line sight paths between adjacent base stations will drive up inter cell interference and reduce efficiency. By using antennas with steep down tilt or antennas placed at low height above ground level (where it is possible to do so) it may be possible to reduce this interference risk.

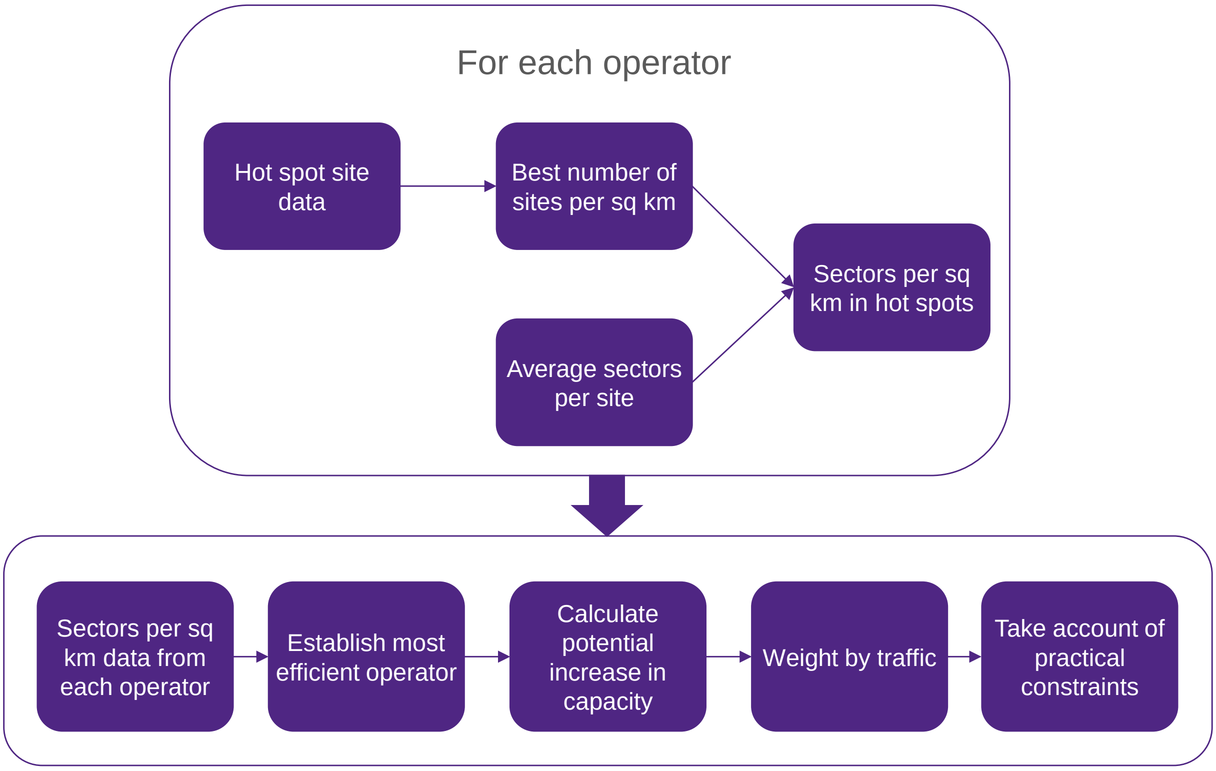
[37] We observed that there is a trade-off between the site spacing and the number of sectors that are deployed in hotspot areas due to the increase in inter sector and inter cell interference as the distance between sites/sectors decreases

[38] Guidance Note for Submission of Application for Installing Micro-cell Base Station on Highway Facilities or on Unleased and Unallocated Governmental Land. See http://www.coms-auth.hk/filemanager/statement/en/upload/119/MCBS-GN(Issue4)v4.pdf

[39] Guidance Note for Submission of Applications by Operators for the Installation of Radio Base Stations for Public Telecommunications Services in Buildings and on Rooftops.
See http://www.coms-auth.hk/filemanager/statement/en/upload/138/gn_201024.pdf

traffic areas (e.g. Central, Wan Chai, Causeway Bay and Mongkok) by establishing for each operator the highest number of sectors deployed per sq km and then looking at the increase in sectors that could be achieved if each operator were to increase site density or sectorisation to the highest level currently implemented by any operator.

Figure A-3: Methodology



We found that practical constraints are likely to prevent this major increases network capacity in the busiest areas (due to difficulties with gaining access to suitable roof top and podium sites and with the deployment of street level sites) and that the increased level of interference resulting from such closer site spacing is likely to negate any benefits. Although capacity increases are unlikely, we consider it prudent to consider an optimistic capacity scenario where a 27% capacity improvement may be achieved, for the purposes of sensitivity checking our conclusions.

Overall potential for 3g capacity increase in outdoor areas

Our assessment of the 3g operators' network deployments suggests that all of the Hong Kong operators are operating at close to the maximum spectral efficiency that it is practical to implement (i.e. a downlink spectral efficiency of 0.41bps/Hz/cell) as described in Appendix A.

Comparison of the spectrum utilised by individual operators suggests that the use of 900 MHz spectrum currently not used for 3g could generate an overall increase of 6% in 3g capacity. However, in reality, it is likely that the 900 MHz spectrum currently used for 3g services would be refarmed for support of 4g services. This would then reduce the spectrum available for 3g and exacerbate the impact of spectrum deprival. In our baseline case we have nevertheless, for simplicity's sake, assumed that all the 900 MHz spectrum is used for 3g services.

It is unlikely that 3g capacity can be increased by increasing the density of sites and sectorisation in the areas having highest traffic density. However if provision of access could be mandated to roof tops and the procedures for building street level sites made more responsive for mobile operators then it may be theoretically possible to achieve a further 27% improvement in 3g capacity by increasing the sector density for all operators to the same high level. Our baseline case assumes that further increases in site density cannot be achieved, but we have also considered an optimistic capacity scenario which includes the 27% improvement.

Together these effects result in two scenarios for 3g capacity improvement in the outdoor network:

- A baseline scenario where capacity can increase from 2012 levels by 6%, and
- An optimistic capacity scenario where capacity can increase from 2012 levels by 35%[40].

A.3 Maximum 3g network capacity on the MTR

The mobile operators provide full coverage of the MTR system in conjunction with MTR Corporation Limited. The system supports 2g and 3g services at present and is in the process of being upgraded to accommodate 4g services using the 1800 MHz band.

The mobile system coverage of the MTR can be considered in two distinct parts:

- The tunnels which are served by leaky coaxial cable; and
- The concourse systems which are typically served by distributed antenna systems.

Each system is finely engineered to provide coverage over its designated area for each of the mobile frequency bands implemented and the specific frequency holdings for each operator. Further upgrade of the network to accommodate the 2.3 and 2.6 GHz bands (based on LTE technology) would require replacement of the leaky coaxial cable; work has not yet started on this upgrade step.

Each antenna system is served by a Point of Insertion (POI) which comprises housing for the mobile operator equipment and a filter/combiner system which combines the signals from each mobile operator into a common feed into the antenna system.

The tunnels and concourse systems present different challenges. Each is considered in turn below.

Concourse systems

The concourse systems use multiple directional antennas to provide coverage of the platforms, ticket halls and access corridors. It is possible to increase capacity in the concourse areas by adding more POIs thereby reducing the physical area covered by each POI. Although it is technically feasible to do this there are practical and commercial difficulties associated with increasing capacity in a timely manner.

- Experience of upgrading the MTR mobile coverage systems has shown that it can take up to 3 years to complete an upgrade program (comprising one year for the design and feasibility stage

[40] i.e. (1.06 x 1.27) = 1.35

and two years for implementation). The delay in this process is partly due to the comparatively slow approval process in the rail environment and the limited available installation time (which must necessarily occur during periods when trains are not running and stations not used).

- The cost of upgrading mobile coverage systems on the MTR has historically been borne by the mobile operators themselves. Each shares the cost of the upgrade program and where the upgrade is to meet specific requirements of an individual operator then that individual operator would have to bear the total cost of the change.

We have assumed that all operators are similarly motivated to upgrade the MTR concourse systems in response to rising traffic levels and that this will be undertaken in response to anticipated growth in 3g traffic. Performance levels for 3g similar to those in the outdoor environment should be achievable in MTR concourse areas but only after a considerable time lag resulting from the practical constraints of doing so. As a result, MTR concourse systems may not be upgraded in time to cater for the rising traffic levels for 3g data.

Tunnel systems

Tunnel systems use a single cable for the transmit direction and a second cable for the receive direction. The layout varies depending upon when the tunnels were built:

- The new lines to the airport and the West Rail extension have one pair of cables designed to accommodate the 850/900/1800/2100 MHz bands used for mobile communications in Hong Kong
- The remaining lines have two pairs of cables serving 850/900 MHz and 1800/2100 MHz respectively.

The POIs for the tunnel systems currently provide access for the 3g operators. The tunnel systems operate under greater technical/practical constraints than the concourse systems. First and foremost of these is that cell splitting is far more difficult and has limited impact.

The mobile systems are divided into sectors at each station such that each sector serves one line output from the station. Therefore a MTR station will have typically two tunnel sectors but may have more if the station serves more than one MTR line.

Creation of new tunnel sectors

To create additional tunnel sectors would require a new POI at a central feed location between stations. The difficulties with increasing capacity in this way are:

- It would be expensive to implement and the changes would only be countenanced where the cost was shared amongst all mobile operators
- It would involve long delays for installation since this is limited to the times that trains do not run (i.e. during the night)
- It would increase the number of handovers in the tunnels therefore the incremental capacity provided would be limited only to those cable segments where handover is not in progress
- There is typically only a single MTR train in each sector at any moment in time and it is the traffic on a single train which poses the greatest traffic load. The movement of a train through additional sectors would not change the peak traffic load on any individual cell.

For the above reasons we believe that changes to the tunnel systems will be undertaken when required by changes in spectrum holdings for the majority of operators (e.g. when there is new spectrum release). We would not expect there to be changes to the tunnel systems in response to a change in a single operator's spectrum holdings or to increase the number of POIs. Accordingly, this means that there would unlikely be any changes made to the tunnel systems if it is simply to accommodate one particular operator's acquisition of 3g spectrum.

3g uplink performance in tunnels

Tunnel systems also pose significant challenges for 3g technology under high traffic loading conditions resulting from uplink noise problems. This is a known phenomenon with 3g technology and it results from the increasing noise level into the uplink cable as the cell becomes heavily loaded. This creates a high noise input into the base station receiver, which in turns degrades its ability to decode data streams and consequently degrades the performance of the cell.

This situation occurs when many devices attempt to communicate with the base station at once and the base station is unable to decode some of the received data streams – if a device does not receive an acknowledgement to its transmitted data stream it will retransmit it at a higher power. If many devices do this simultaneously the noise level at the base station receiver increases. The problem is exacerbated when all of the transmitting devices are in a confined space such as a train where the noise sources are in close proximity to one another and to the receive cable running along the tunnel wall. The 3g operators have observed this problem occurring on their networks under heavy loading conditions. The problem is also observed outside of the tunnels where the MTR runs through outdoor hotspots.

In addition, all 4g handsets currently use the 3g network for voice communications which will exacerbate the uplink noise problem. Although Voice over LTE (VoLTE) standards should be implemented in the 4g networks by 2016, the additional uplink noise contributed by 4g terminals on the MTR will not be reduced until new VoLTE capable handsets become a significant proportion of total 4g handsets. However, the non-VoLTE capable handsets will continue to be present even then, through the second hand phone markets.

The occasional failure of 3g communications on the MTR due to the uplink noise problem in busy commuting times, demonstrates that 3g voice and mobile data service availability is highly sensitive to the number of both 3g and 4g users in the tunnels. This occasional outage even without spectrum deprival shows that 3g networks area highly reliant on all the 2.1 GHz spectrum being available for provision of 3g services.

A.4 Maximum 3g network capacity for indoor systems

There are many indoor mobile systems in Hong Kong in both residential (e.g. apartment buildings) and commercial buildings (e.g. shopping malls, hotels and offices). In general provision of indoor coverage faces similar problems to the MTR (e.g. planning, being able to gain access to do the work), although the problems are not as severe. Lead times are generally shorter but there can still be issues associated with access and cost, especially in locations such as shopping malls where work may have to be scheduled to be carried out when visitors are not present.

Coverage provided by indoor systems is not universal:

- Residential buildings: Operators usually attempt to cover the common areas and corridors of these buildings where there is demand to do so. However, this will not always result in good coverage for residents in their apartments. This results in operators having to use a mix of indoor systems and cells in the outdoor network to provide adequate coverage.
- Commercial buildings: Again operators attempt to cover common areas of such buildings (e.g. walkways within shopping malls, hotel lobby areas). Within a mall, for example, provision of coverage inside shops will depend on whether the mobile operator has an agreement in place with the mall owner (if this is not provided as part of the overall building coverage). Where there are gaps in the coverage provided in commercial buildings there is again a requirement for traffic to be served through a combination of the building network and cells in the outdoor network.

Note that commercial buildings and malls associated with one 3g operator may create particular access and coverage issues for non-associated 3g operators.

A.5 Other 3g enhancements and complementary technologies

We also considered whether 3g technology enhancements or other technologies could further improve the capacity of 3G networks. All of the 3g operators have deployed HSPA+ in their network, which has enabled the benefits of 64QAM coding and dual carrier operation. Other considerations are:

- Multiple Input Multiple Output (MIMO) antennas – although the use of MIMO is standardised for 3g and has been implemented by at least one of the 3G operators, further deployment would do little to improve the overall capacity of 3G networks in Hong Kong. Effective improvements in spectrum efficiency rely on MIMO technology also being deployed in mobile devices, and MIMO has yet to find its way into the 3g device ecosystem.
- Femto cells provide an alternative means to provide coverage in domestic environments (e.g. houses or apartments) and possibly some smaller commercial premises. In such environments femto cells may provide a more robust alternative to Wi-Fi through delivery of a managed and more secure service. However they are unlikely to do more than act as another means of offload since they generally operate in a small defined space and rely on the public fixed broadband network for backhaul to the mobile operators network (other small cell installations will be directly connected to the mobile operator’s network). Also, the decision to deploy a femto cell is usually taken by the tenant of the premises and their installation is not therefore generally part of a systematic network capacity plan.
- Heterogeneous networks (Hetnets) potentially deliver a high quality mobile broadband experience using a hybrid of macro cells, small cells (micro, pico, femto) and possibly Wi-Fi. Hetnets are likely to be implemented using LTE technology but HSPA+ cells could also be part of a hetnet system. Key to deploying a hetnet is the ability to deploy many small cells to create a very high density network where traffic is highest and the implementation of a more intelligent system control plane to optimise traffic, manage cell use and handover requirements. The key constraints for implementing hetnets in Hong Kong would be those already mentioned for deployment of small cells in street and other public environments.
- Public WiFi – the deployment of public WiFi in Hong Kong has grown steadily since 2007 to more than 6000 registered wifi zones and 19,000 access points. In most cases the use of WiFi is a

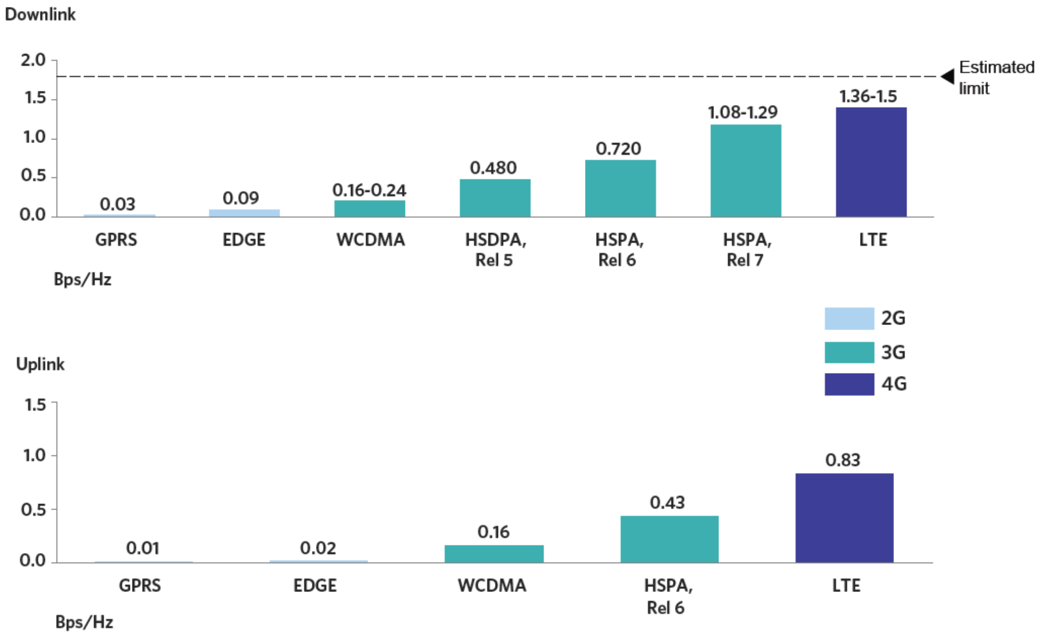
subscriber decision and subscribers are motivated to maximise their use of WiFi to reduce their mobile usage costs. This includes use of WiFi at home and where possible in public WiFi hotspots. The difficulty with WiFi is that it has limited range and suffers from interference in high density environments when used outdoors. Consequently we expect WiFi use to continue to be popular where users are indoors and stationary. We do not believe that public WiFi provides an effective means for 3g operators to supplement downlink capacity within their networks.

Appendix B: Spectral efficiency

The spectral efficiency of mobile technology is a measure of the data throughput that can be achieved for a given unit of spectrum. It is usually measured in terms of the average bits per second per Hz per cell (bps/Hz/cell) where a cell is a single sector on a multi-sector site. The spectral efficiency varies with different mobile technologies and typically improves as more sophisticated features are added with each release of standards.

Estimates of the network spectral efficiency for the 3GPP family of standards are shown in Figure B-1 which have been used as the basis for the FCC Broadband Plan.[41] This shows the steady improvement in spectral efficiency that has been achieved with each release of 3GPP standards.

Figure B-1: Spectral efficiency by technology (in bps/Hz/sector) relative to an estimate of the Shannon limit (the theoretical maximum achievable on a single channel)



Source: FCC national broadband plan

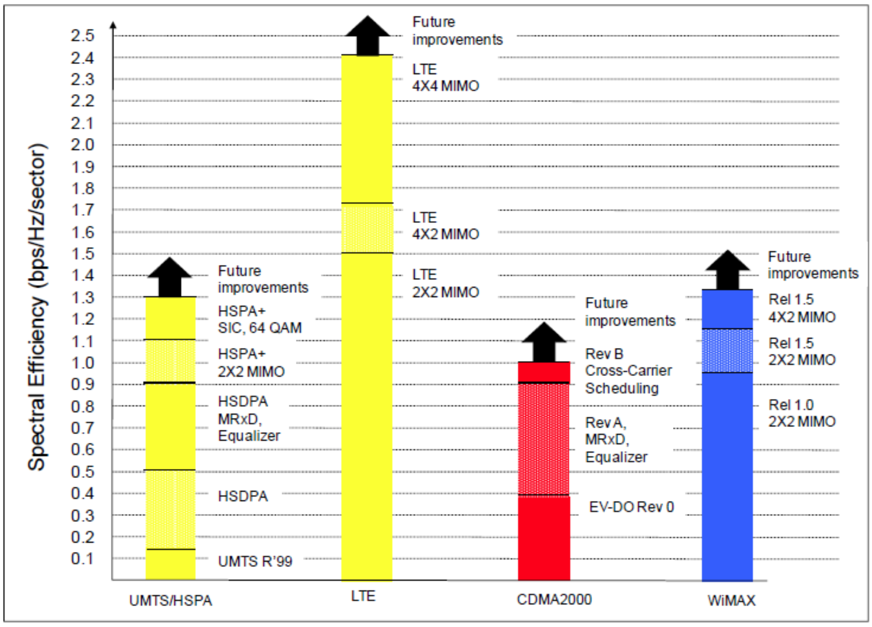
According to the FCC, the spectrum efficiency for HSPA is expected to peak at around 1.08 to 1.29 bps/Hz/cell in the downlink. However, this is conditional on Release 7 of the 3GPP standards which includes 2x2 MIMO to justify the upper end of the range (2x2 MIMO on HSPA cannot be effective in Hong Kong unless MIMO technologies are introduced into the 3g device ecosystem and as discussed in Section 2 this is unlikely to happen). The lower end of the range includes 64 QAM which has already been deployed in Hong Kong.

A similar improvement is predicted by 3G Americas.[42] The 3G Americas estimates of the downlink spectral efficiencies are shown in Figure B-2 for a variety of technologies.

[41] http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf

[42] HSPA to LTE-Advanced: 3GPP Broadband Evolution to LTE-Advanced (4G), Rysavy Research, September 2009

Figure B-2: Comparison of downlink practical network spectral efficiency



Source: Rysavy Research, 3G Americas

The above studies suggest that the network efficiency of HSPA will peak at around 1.0 bps/Hz/cell. The 3G Americas report also makes the point that practical network spectral efficiency is typically lower than theoretical values derived from network simulation such as those indicated by 3GPP.

When using spectral efficiency to assess impacts on real networks, it is important to distinguish between theoretical measures and practical measures that can be achieved in real network conditions. The practical network spectral efficiency should be used for estimation of spectrum requirements and allocation decisions. For example factors that may influence the difference between theoretical and practical spectral efficiency include:

- The inefficiency associated with not being able to optimally place sites to meet traffic demand – in previous studies we have estimated the useable capacity may be 70% of the total, due to mismatch between the traffic demand and deployed capacity
- The need to deploy capacity in large increments – each unit of 3g capacity is deployed as a 2x5 MHz block of spectrum. In practice, we would not expect each block to be efficiently occupied in a network that is constantly being refined to adjust to changing traffic needs. Typical occupancy may be as low as 80% resulting an average occupancy of 90%.

Together these practical effects in real networks can reduce network spectral efficiency to 63%[43] of its theoretical value which suggests a mean spectral efficiency of 0.63 bps/Hz/cell.

To get a better appreciation of practical network impacts work has been undertaken in the UK by Real Wireless for Ofcom[44]. Real Wireless has published spectral efficiency values for different technology releases (based on 3gpp releases) against high end, typical and low end device scenarios. The technical configurations considered by Real Wireless are shown in Table B-1 and the resulting downlink spectral efficiency values in Table B-2. The high end device scenarios rely on various

[43] This is calculated as (1 – 0.3) x (1 – 0.1) = 0.63

[44] Real Wireless – Report for Ofcom: 4G capacity gains, 27th January 2011

implementations of MIMO techniques, which are unlikely to be prevalent in the near term. In practice spectral efficiency in a deployed macro network situation is more likely to fall in the range bounded by the low end and typical expected roll out values.

Table B-1: High end, typical and low end technical configurations

	HSPA Release 5	HSPA Release 6	HSPA + Release 7/8	LTE Release 8	LTE-A Release 10
High end	MIMO1x2 (Rx div), 15 codes, 64QAM	MIMO 1x2 (Rx div), 15 codes, 64QAM	MIMO 2x2, 15 codes, 64QAM	SUMIMO 4x4	JPCoMP 8x4
Typical expected rollout	MIMO 1x2 (Rx div), 15 codes, 16QAM	MIMO1x2 (Rx div), 15 codes, 16QAM	MIMO 1x2 (Rx div), 15 codes, 16QAM	SUMIMO 2x2	MUMIMO 4x2
Low end	SISO 1x1, 5 codes, 16QAM	SISO 1x1, 5 codes, 16QAM	SISO 1x1, 5 codes, 16QAM	MIMO 1x2 (Rx div)	SUMIMO 2x2

Source: Real Wireless

Table B-2: Downlink spectral efficiency values

	HSPA Release 5	HSPA Release 6	HSPA + Release 7/8	LTE Release 8	LTE-A Release 10
High end	0.50	0.76	1.13	2.08	5.44
Typical expected rollout	0.45	0.68	0.68	1.32	2.6
Low end	0.28	0.41	0.41	1.12	2.09

Source: Real Wireless

Taken together this evidence suggests that a downlink spectral efficiency of 0.41bps/Hz/cell might be the best 3g performance that is achievable in the high traffic density areas of Hong Kong where outdoor cells are sited very close to one another and interference is likely to be a design issue for the network . This finding is consistent with the feedback we received from talking to the 3g operators. For example, one operator told us that under the highest traffic load conditions in their hot spot areas they were achieving traffic throughputs that are consistent with this assumption when they operate their cells with a defined level of headroom to maintain an acceptable quality of service (i.e. users can expect 1 mbps of download throughput during the busy hour with a blocking rate of less than 5%).

Given that network deployments (layout and equipment) are broadly similar across the 3g operators in the densest traffic areas of Hong Kong we have used a downlink spectrum efficiency of 0.41bps/Hz/cell in our modelling of capacity of the operators' networks.