Technical Study in relation to the Re-assignment of Spectrum in the 900 MHz and 1800 MHz Bands upon Expiry of the Existing Assignments

Public version

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Executive summary

Plum Consulting London LLP (Plum) has been commissioned by the Office of the Communications Authority (OFCA) on behalf of the Communications Authority (CA) to conduct a technical study (Study) in support of the public consultation on the arrangements for the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands upon expiry of the existing assignments for provision of public mobile telecommunications services in 2020/21.

This Study provides an independent and objective assessment of the impacts on service quality arising from the spectrum re-assignment. Plum has carried out a quantitative analysis of the potential impact of changes of spectrum assignment in these bands based on sound modelling techniques and input assumptions supported by other research and qualitative analysis.

S.1 Current situation on spectrum holdings

In Hong Kong, a total of 552 MHz of spectrum is assigned for the provision of public mobile telecommunications services as of end October 2016.[1] The spectrum holdings of each mobile network operator (MNO) (as at 22 October 2016) are as follows:

- Hong Kong Telecommunications (HKT) Limited (HKT): 174 MHz
- China Mobile Hong Kong Company Limited (CMHK): 116 MHz
- SmarTone Mobile Communications Limited (SMT): 112.6 MHz
- Hutchison Telephone Company Limited (HTCL): 109.4 MHz
- Genius Brand Limited (GBL): 40 MHz.

HKT holds the largest spectrum portfolio and it has considerably more spectrum in the 1800 MHz band than its competitors, largely due to its acquisition of the former CSL New World Mobility Limited. Among the 552 MHz spectrum, a total of 198.6 MHz of spectrum, comprising 49.8 MHz in the 900 MHz band and another 148.8 MHz in the 1800 MHz band, is due to expire between 19 November 2020 and 29 September 2021 (representing 36% of the total spectrum so far assigned for the provision of public mobile telecommunications services in

[1] The amount of 552 MHz spectrum for mobile services does not include 8 MHz of spectrum (678 – 686 MHz) assigned to Hong Kong Mobile Television Network Limited for the provision of broadcast-type mobile television services, 30 MHz of unpaired spectrum in the 2.3 GHz band assigned in 2012 and deployed for the provision of wireless fixed broadband services, 20 MHz of unpaired spectrum in the 1.9 – 2.2 GHz band assigned in 2001 which was left idle throughout the assignment period of 15 years and was put back to reserve at the end of the assignment term in October 2016, and 9.7 MHz of unpaired spectrum in 2010 – 2019.7 MHz for the provision of public mobile telecommunications services that was put out for auction in February/March 2011 but was left over because of no interested bidder.

Hong Kong). Also, taking account of the 0.2 MHz of spectrum in the 900 MHz band and 1.2 MHz of spectrum in the 1800 MHz band which is currently vacant, a total of 200 MHz of spectrum[2] will be covered under this spectrum re-assignment exercise. At present, there is a mix of 2G, 3G and 4G technologies deployed in the 900 MHz and 1800 MHz bands. Table 1 shows the current assignments of the frequency spectrum for mobile services to the incumbent MNOs.

Table 1: Spectrum holdings in mobile bands (as at 22 October 2016)

MNO	850/900 (MHz) (1)	900 (MHz)	1800 (MHz)	2100 (MHz)	2300 (MHz)	2600 (MHz)	Total (MHz)
HKT	2×7.5	2×8.3	2×36.4	2×14.8		2×20	174
HTCL	2×5	2×8.3	2×11.6	2×14.8	1×30		109.4
CMHK			2×13.2	2×9.8	1×30	2×20	116
SMT	2×5	2×8.3	2×13.2	2×19.8		2×10	112.6
GBL						2×20(2)	40
Total	2×17.5	2×24.9	2×74.4	2×59.2	1×60	2×70	552

Notes to Table 1:

(1) This spectrum re-assignment exercise does not involve the spectrum assigned to HTCL in the EGSM band (885 – 890/930 – 935 MHz) and to SMT and HKT in the 850 MHz band (i.e. 832.5 – 837.5/877.5 – 882.5 MHz and 825 – 832.5/870 – 877.5 MHz respectively);

(2) The spectrum held by GBL is deemed to be shared equally between HKT and HTCL for the purpose of this Study.

Source: OFCA

S.2 Assessment model

Plum's approach to undertaking the assessment involves a combination of market forecasting and technical modelling. For the purpose of the Study, Plum has requested information from each MNO on historical mobile network traffic, existing infrastructure and coverage, utilisation of assigned spectrum as well as development plans on new services and technologies. Each MNO has also been required to provide its future projections for network traffic by technology and for infrastructure and spectrum utilisation during the forecast period. Plum has suitably adjusted the information in consultation with the MNOs, having regard to relevant information and forecasts of international bodies.

[2] It consists of 2×25 MHz in the frequency ranges of 890 – 915 MHz paired with 935 – 960 MHz, and 2×75 MHz in the frequency ranges of 1710 – 1785 MHz paired with 1805 – 1880 MHz.

S.2.1 Methodology of the assessment model

The assessment model has been developed using a spreadsheet based model. It analyses the network infrastructure requirements in respect of the traffic demand under various market development, technology evolution and spectrum availability scenarios on a territory-wide basis and in the high traffic areas. The busiest 20% of sites are considered as the high traffic areas which are assumed to carry 60% of all the network traffic. The assessment model also analyses the service impact on a per operator and per technology basis.

The assessment model estimates the network capacity based on the existing network infrastructure of each MNO. It then compares the estimated network capacity with busy hour traffic demand. This process is carried out for each of the identified scenarios (see S.2.3 below) in which the MNOs are assigned different amounts of spectrum in the 900 MHz and 1800 MHz bands as a result of the spectrum re-assignment. The modelling period covers a time span of eight years from 2016 to 2023. As the spectrum re-assignment is assumed to take place in 2021[3], the assessment model has catered for the situation for two years post the re-assignment.

S.2.2 Output of the assessment model

The output of the assessment model is expressed as Demand Capacity Overage (DCO)[4], which shows the percentage of demand that is unable to be met by network design capacity. For the calculation of DCO, the maximum allowable network loading threshold is set as 80% of the total network capacity under normal operating conditions. A zero DCO calculated for a particular scenario would indicate that the traffic demand is less than 80% of the total network capacity, whereas a positive DCO would indicate excessive traffic demand beyond 80% of the total network capacity which implies the possibility of potential impacts on service quality.

S.2.3 Scenarios used in the assessment model

The scenarios used in the assessment model reflect different distributions of spectrum between the MNOs depending on the result of the spectrum re-assignment. The assessment has considered likely spectrum scenarios which are shown in Table 2 below. These include a

[3] The assignment period for the spectrum in the 1800 MHz band ends on 29 September 2021 whereas that for the spectrum in the 900 MHz band expires between 19 November 2020 and 11 January 2021. According to the first consultation paper jointly issued by the CA and the Secretary for Commerce and Economic Development on the subject matter on 3 February 2016, the CA proposed to align the new assignment period for all the concerned spectrum in the 900 MHz band so that they would all commence on 11 January 2021. Based on this, the spectrum re-assignment is assumed to take place in 2021 for the purpose of this Study.

[4] DCO was the measure used in the previous study in 2013 in relation to the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band in Hong Kong. Since the DCO was extensively discussed in the above-mentioned spectrum re-assignment exercise, for the sake of consistency and easy understanding by the general public, presentation of the results of this Study to the public is also based on the DCO.

number of possible situations ranging from no change in current assignments to spectrum reshuffling among the incumbent MNOs (without a new entrant to the Hong Kong market) and spectrum reshuffling among the incumbent MNOs and a new entrant in the Hong Kong market. The scenario with a new entrant (Scenario 6) is further split into 5 sub-scenarios (i.e. Scenarios 6A to 6E) that assume different amounts of spectrum are acquired by the new entrant from the incumbent MNOs.

Table 2: Spectrum scenarios used in assessment

Scenarios	Notes
1. Base case (status quo) – No change in current assignments	All MNOs are assumed to retain their current holdings in the frequency spectrum in the 900 MHz and 1800 MHz bands. This status quo scenario is considered as the counterfactual or base case.
2. Spectrum re-assigned in current proportions but defragmented	All MNOs retain current amounts of spectrum but the holdings are defragmented to allow more efficient spectrum use.
3. Spectrum re-shuffling among incumbent MNOs involving 2×20 MHz of spectrum in total	The MNOs end up with different amounts of spectrum post re-assignment. Under this scenario, two MNOs would lose some of their existing spectrum holdings to [✂….].
4. Spectrum re-shuffling among incumbent MNOs involving 2×15 MHz of spectrum in total	The MNOs end up with different amounts of spectrum post re-assignment. Under this scenario, [✂….] would lose some of its existing spectrum holding to [✂….].
5. Spectrum assignments reflect MNO market share	The MNOs acquire amounts of spectrum which are in line with their share of mobile traffic. The rationale is that spectrum acquisition is driven primarily by the traffic demand situation at the time of re-assignment.
6A to 6E. A new entrant acquires spectrum	In each scenario, a new entrant acquires spectrum in the auction, reducing the total spectrum holdings of the incumbent MNOs to varying degrees. Five different cases are considered. 6A. New entrant acquires 2×20 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….] 6B. New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….] 6C. New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….] 6D. New entrant acquires 2×10 MHz currently held by [✂….] 6E. New entrant acquires 2×10 MHz currently held by [✂….], 2×5 MHz currently held by [✂….], 2×5 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]

S.2.4 Use of mitigating measures

Even when the DCO calculated by the assessment model shows that service quality issues may potentially occur for any particular scenario, it does not necessarily mean that the actual service quality offered by a particular MNO will be unacceptably impaired under that scenario, as the MNO can implement a number of mitigating measures to cope with the network traffic. There are a number of ways to mitigate, including increasing the capacity of the network (e.g. by adding more sectors), and offloading excess traffic onto another network (e.g. Wi-Fi offloading). If the service quality problem is specific to 2G or 3G networks, the mitigation can also be to refarm the spectrum to a more efficient technology (4G) and to migrate 2G and 3G customers to 4G. The practicability and effect of each mitigation approach will vary depending on the actual network circumstances and there may be trade-offs between different solutions.

S.3 Output of the assessment model

S.3.1 Analysis for all MNOs – territory-wide and high traffic areas

For all MNOs as a whole, the Study shows that there is sufficient network capacity to accommodate all traffic demands in all scenarios, both territory wide network and in high traffic areas. A summary of the assessment model results for all MNOs by technology is set out below:

- **2G services**

  The Study shows that the spectrum assumed to be retained for 2G services (i.e. [✂….] MHz based on the input of [✂….] and [✂….] MHz based on the inputs of the [✂….]) is sufficient to safeguard the continuity of 2G services after the spectrum re-assignment under all scenarios.

- **3G services**

  The Study shows that the spectrum re-assignment does not have a significant impact on service quality and that service continuity is maintained in all scenarios. The MNOs should have sufficient spectrum in the 1.9 – 2.2 GHz band to sustain 3G traffic and safeguard the provision of 3G services, provided that some MNOs may have to retain more spectrum in the 1.9 – 2.2 GHz band for 3G services than others or have to migrate more 3G users to 4G platforms.

- **4G services**

  The Study shows that the spectrum re-assignment does not have a significant impact on service quality and that in general service continuity is maintained in all scenarios for all MNOs at both territory-wide and high traffic areas.

S.3.2 Analysis for specific MNOs

For each of the MNOs, the Study shows that the spectrum re-assignment does not have a significant service impact in all scenarios on a territory-wide basis. On the other hand, in high traffic areas, there are some specific scenarios in which certain MNOs will individually experience potential impacts on service quality for 3G or 4G services. However, appropriate mitigating measures can be used to resolve or alleviate the concerned service impacts. A summary of the assessment model results for specific MNOs by technology in high traffic areas is set out below:

- **2G services**

  The Study shows that there is no service impact for any of the individual MNOs in all scenarios.

- **3G services**

  MNO2 is the only MNO which may face minor service quality issue for 3G services in high traffic areas under the Study. With the retention of [✂….] MHz of the 1.9 – 2.2 GHz band for 3G services from 2021 onwards, the 3G DCO result of MNO2 will be 4% in 2021. This can be mitigated by a delay to the refarming of spectrum in the 1.9 – 2.2 GHz band by at least another year, say by retaining [✂….] MHz of the 1.9 – 2.2 GHz band for 3G services until 2022 or later. This mitigating measure will improve the DCO to an acceptable level. While this mitigation will eliminate the 3G service quality issue, retaining [✂….] MHz of the 1.9 – 2.2 GHz band for 3G services until 2022 or later is likely to be an inefficient use of spectrum and it may cause possible 4G service quality issues for MNO2. In practice, it is more likely that MNO2 will seek to migrate traffic from its 3G network to 4G.

- **4G services**

  MNO1 and MNO2 are the only MNOs which may individually experience slight or marginal service quality issues at high traffic areas in 2023 under certain specific scenarios with a new entrant.

  The 4G DCO results for MNO1 indicate that MNO1 may experience service quality issues in high traffic areas in 2023 in Scenario 6A [✂….]. In this scenario, the 4G DCO result of MNO1 is 14.6%. With the adoption of mitigating measures such as by increasing the number of sectors and with more Wi-Fi offload, the DCO figure can be reduced to 0%.

  The 4G DCO results for MNO2 indicate that it will face potential service quality issues in high traffic areas in 2023 in Scenario 6B where the new entrant acquires 2×15 MHz of spectrum currently held by [✂….]. In this scenario, the 4G DCO result of MNO2 is 4.3%. The retention of [✂….] MHz of the 1.9 – 2.2 GHz band for 3G services until 2022 will aggravate 4G service quality issues for MNO2 in the 2021-23 period. However, this can be mitigated by increasing the number of sectors deployed in 4G high traffic areas and hence, the 4G DCO will be reduced to 0%.

S.3.3 Sensitivity Analysis

The sensitivity analysis in cases of using a high traffic forecast, increase/decrease in total number of sites by 10% and no improvement in 4G spectrum efficiency throughout the modelling period was conducted. The sensitivity checks, especially for those cases that are expected to have impacts on service quality, show that with one small exception (high traffic forecast under Scenario 6) there is a reasonable margin of safety with the assessment model results. This exception can be mitigated by increasing the number of sectors and/or increasing Wi-Fi offload.

S.4 Impacts on the continuity of mobile services at Mass Transit Railway (MTR) premises

S.4.1 Mobile environment and Integrated Radio Systems (IRS) at MTR premises

The MTR is a special mobile environment in terms of the design of network infrastructure for the provision of mobile coverage. It is predominantly a high traffic indoor system operating in confined spaces (on station concourses, platforms and in rail tunnels). The constraints of such an environment lead to difficulty in applying the assessment model, which is designed to reflect the operation of a large network with the capacity of all the base stations considered on an aggregate basis. Plum has therefore carried out a qualitative analysis of issues for the MTR.

Mobile services at MTR premises are currently provided by IRS, which are common radio signal distribution systems operating in the 900 MHz, 1800 MHz and 1.9 – 2.2 GHz bands and installed at stations, platforms and tunnels for carrying the radio signals for all MNOs. Provision of 4G services at MTR premises primarily relies on part of the 1800 MHz band (i.e. 1720 – 1780/1815 – 1875 MHz). At present, there is already a concrete plan for MTR to upgrade the IRS at 18 prime stations with high passenger flow to include 2.3 GHz and 2.5/2.6 GHz bands for supporting 4G services with frequency agile equipment by 2019. However, there is yet to be any agreement between MNOs and the MTR Corporation Limited (MTRC) about upgrade of the IRS in 43 MTR stations and the adjoining tunnels (Remaining Stations).

Furthermore, any reconfiguration of the operating frequency bands in the IRS requires time for testing and system commissioning and there is a limitation on the time available for engineering and testing work to be carried out each day at MTR premises. It is noted that a transitional period will be needed for any such reconfiguration during which radio transmission over the concerned frequency band may be interrupted.

S.4.2 Potential impacts on service continuity post re-assignment

Taking into account the future upgrades to be implemented for the IRS, Plum has considered the impact of the spectrum re-assignment for the following cases:

- **Stations with IRS that have been upgraded with frequency agile equipment and in addition support the 2.3 GHz and 2.5/2.6 GHz bands**

  The potential impacts on 4G service continuity at these stations when spectrum re-assignment occurs should be minimal or acceptable.

- **Remaining Stations with IRS that have not been upgraded (i.e. not support the 2.3 GHz and 2.5/2.6 GHz bands) and are reliant on legacy equipment which is not frequency agile**

  4G service continuity at these MTR stations and adjoining tunnels may likely be affected if the new spectrum assignments do not align with the existing equipment configuration and/or a MNO fails to retain any of its existing spectrum holding, as a long lead time will be required to reconfigure or upgrade the IRS in the Remaining Stations which may range from three months for system re-configuration or up to three years if full system upgrade is needed. A lengthy transitional period means that service users will be adversely affected on a prolonged basis. Users of the 3G network will also be affected as the 4G mobile data users will migrate onto the 3G network when the 4G services are interrupted.

S.4.3 Recommendation on the Right of First Refusal (RFR) spectrum

A possible solution to this problem could be that each incumbent MNO will be offered 2×10 MHz of spectrum in the 1800 MHz band on a RFR basis so that such re-assignments are within the frequency range of 1720 – 1780 / 1815 – 1875 MHz.[5] This will allow the MNOs to ensure the provision of 4G services at the Remaining Stations, and lower the congestion likely to be encountered arising from the spectrum re-assignment as the RFR spectrum can continue to be utilised right after the spectrum re-assignment. This approach will still provide a total of 2×60 MHz spectrum (2×35 MHz in the 1800 MHz band and 2×25 MHz in the 900 MHz band) to be re-assigned by auction.

An alternative will be to permit only 2×5 MHz to be re-assigned to each MNO on an RFR basis in the 1800 MHz band. However, it will run the risk that subject to the auction result, MNOs may not be able to retain the 2×10 MHz of the spectrum in the 1800 MHz band currently deployed for provision of 4G services at the Remaining Stations. This approach will provide a total of 2×80 MHz spectrum (2×55 MHz in the 1800 MHz band and 2×25 MHz in the 900 MHz band) to be re-assigned by auction.

[5] This frequency range is the band of the legacy 1800 MHz IRS equipment deployed at MTR premises.

S.5 Conclusion

In this Study, an independent and objective assessment of the impacts on service quality arising from the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands has been conducted. In summary, the results of the Study indicate that across all of the MNOs as a whole, there is no impact on the quality of 2G, 3G and 4G services for territory-wide network and in high traffic areas under all scenarios considered in the Study. Regarding the networks of individual MNOs, the provision of their 2G, 3G and 4G services on a territory-wide basis will also not be affected by the spectrum re-assignment under Scenarios 1 to 5. Nevertheless, two MNOs may individually encounter minor service quality issues for their respective 3G and/or 4G services for certain specific scenario(s). In any case, it is considered that the concerned MNOs should be able to resolve or alleviate the potential service quality issues by implementing the identified mitigating measures.

In addition, a qualitative assessment for the situation in relation to the provision of mobile services at MTR premises has also been carried out. Based on the findings, it is recommended that 2×10 MHz RFR spectrum in the 1800 MHz band should be offered to each of the incumbent MNOs with a view to maintaining the continuity of 4G services at MTR premises.

1 Introduction

Plum has been commissioned by OFCA on behalf of the CA to conduct a technical study in support of the public consultation on the arrangements for the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands upon expiry of the existing assignments for public mobile telecommunications services in 2020/21. This Study provides an independent and objective assessment of the impacts on service quality arising from the spectrum re-assignment. Plum has carried out a quantitative analysis of the potential impact of changes of spectrum assignment in these bands based on sound modelling techniques and input assumptions supported by other research and qualitative analysis.

1.1 Background of the Study

The detailed scope and plan for the Study are based on a consultancy brief issued by OFCA dated 19 October 2015, which sets out the objectives of the Study as follows:

- Provide an independent and objective quantitative assessment of the impacts on service quality arising from the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands upon expiry of the existing assignments in 2020/21; and

- Offer assistance and advice to the CA in the analysis of technical issues as raised in the submissions received in response to the two rounds of public consultation to be launched by the CA on the re-assignment arrangements, as well as all other submissions received by the CA during the period prior to the promulgation of the CA's final decision on the subject matter in or around end 2017.

The questions specifically set out in the consultancy brief to be addressed by Plum are:

- What would be the overall impacts on the quality of territory-wide 2G, 3G and 4G services of the mobile market as a whole in 2020/21 after the re-assignment, as compared to the base case?

- What would be the impacts on the quality of territory-wide 2G, 3G and 4G services of each of the MNOs in 2020/21 after the re-assignment, as compared to the base case?

- What would be the overall impacts on the quality of 2G, 3G and 4G services of the mobile market as a whole at areas where voice and data traffic is much heavier than the average and/or subject to limitation of capacity expansion, such as the MTR lines and stations, airport terminals and major shopping malls (generally referred to as "high traffic cells") in 2020/21 after the re-assignment, as compared to the base case?

- What would be the impacts on the quality of 2G, 3G and 4G services of each of the MNOs at the high traffic cells in 2020/21 after the re-assignment, as compared to the base case?

- What measures could be adopted by the affected MNOs with a view to mitigating, in a timely manner, the adverse impacts identified above?

OFCA has also set out a number of factors that Plum should take into account in conducting its assessment including the spectrum situation of each MNO, issues arising from the re-assignment of spectrum, mobile data traffic demand forecasts and inbound roaming traffic, technological changes (including Long Term Evolution Advanced (LTE-A) and wider carriers), improvements in spectrum efficiency and the possibility of a new entrant building a network from scratch.

The assessment is undertaken using an assessment model developed by Plum. The assessment model calculates the mobile network capacity available to handle mobile traffic in Hong Kong and compares it with traffic demand. Traffic demand is based on forecasts provided by the MNOs with suitable adjustments made by Plum. The assessment model compares the demand and capacity of each MNO and by each technology (2G, 3G and 4G), and provides an indication of the service quality for each scenario. The results can be derived for the territory wide network and the busiest 20% of sites. The model does the comparison for a set of scenarios of different assignment outcomes for the spectrum in the 900 MHz and 1800 MHz bands for the period from 2016 to 2023.

This report presents the results of each scenario as DCO.[6] DCO is a measure of demand that exceeds the normal loading capacity of the network – it therefore shows the amount of excess demand (see Section 3.6 for more details).

In addition to the assessment model, Plum has also undertaken other research and qualitative analysis to better inform the conclusions presented in this report.

1.2 Current situation of the use of the frequency spectrum in the 900 MHz and 1800 MHz bands

1.2.1 Spectrum holdings by each MNO

The spectrum holdings of each MNO (as at 22 October 2016) are shown in Table 1-1. There are significant differences in the MNOs' spectrum portfolios. For example, HKT has considerably more spectrum in the 1800 MHz band than its competitors, largely due to its acquisition of the former CSL New World Mobility Limited in 2014[7] which had the largest block of spectrum in this band at that time. The spectrum in the 900 MHz and 1800 MHz bands represent around a third of the total bandwidth across all bands licensed for mobile services in Hong Kong.

[6] This was the same metric used for the technical study conducted in 2013 for the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band in Hong Kong.

[7] http://www.coms-auth.hk/filemanager/statement/en/upload/270/decision_20140502_e.pdf

Table 1-1: Spectrum holdings in mobile bands (as at 22 October 2016)

MNO	850/900 (MHz) (1)	900 (MHz)	1800 (MHz)	2100 (MHz)	2300 (MHz)	2600 (MHz)	Total (MHz)
HKT	2×7.5	2×8.3	2×36.4	2×14.8		2×20	174
HTCL	2×5	2×8.3	2×11.6	2×14.8	1×30		109.4
CMHK			2×13.2	2×9.8	1×30	2×20	116
SMT	2×5	2×8.3	2×13.2	2×19.8		2×10	112.6
GBL						2×20(2)	40
Total	2×17.5	2×24.9	2×74.4	2×59.2	1×60	2×70	552

Notes to Table 1-1:

(1) This spectrum re-assignment exercise does not involve the spectrum assigned to HTCL in the EGSM band (885 – 890/930 – 935 MHz) and to SMT and HKT in the 850 MHz band (i.e. 832.5 – 837.5/877.5 – 882.5 MHz and 825 – 832.5/870 – 877.5 MHz respectively);

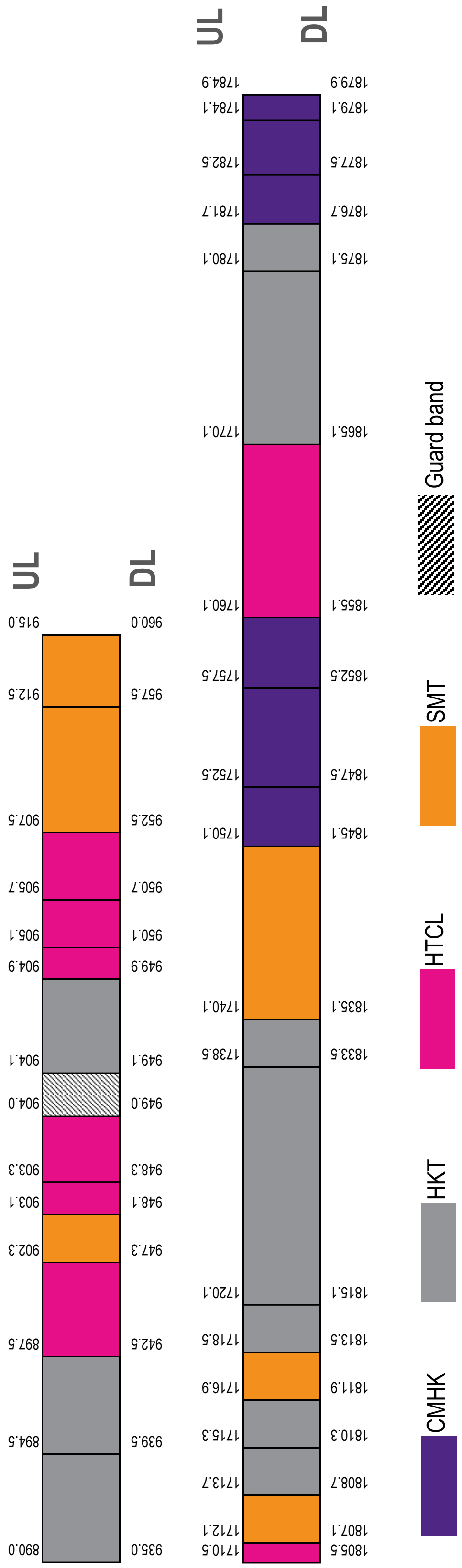
(2) The spectrum held by GBL is deemed to be shared equally between HKT and HTCL for the purpose of this Study.

Source: OFCA

The phased historic assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands combined with the relatively small spectrum packages awarded in some cases has resulted in fragmentation of the spectrum holdings in these bands, as illustrated in Figure 1-1. The CA had previously approved applications from MNOs to swap frequency assignments with a view to achieving technically efficient use of spectrum. For example, CMHK and SMT were allowed to swap some of their spectrum in the 1800 MHz band to create larger contiguous blocks in 2012 [8] – but the remaining fragmentation presents a significant impediment to the deployment of more efficient 4G technologies, especially in the 900 MHz band.

[8] http://www.coms-auth.hk/filemanager/common/policies_regulations/ca_statements/08_2012.pdf

Figure 1-1: Current assignments in the 900 MHz and 1800 MHz bands



At present, there is a mix of 2G, 3G and 4G technologies deployed in the 900 MHz and 1800 MHz bands. The technology use by band is shown in Table 1-2.

Table 1-2: Technology use by band (as at September 2016)

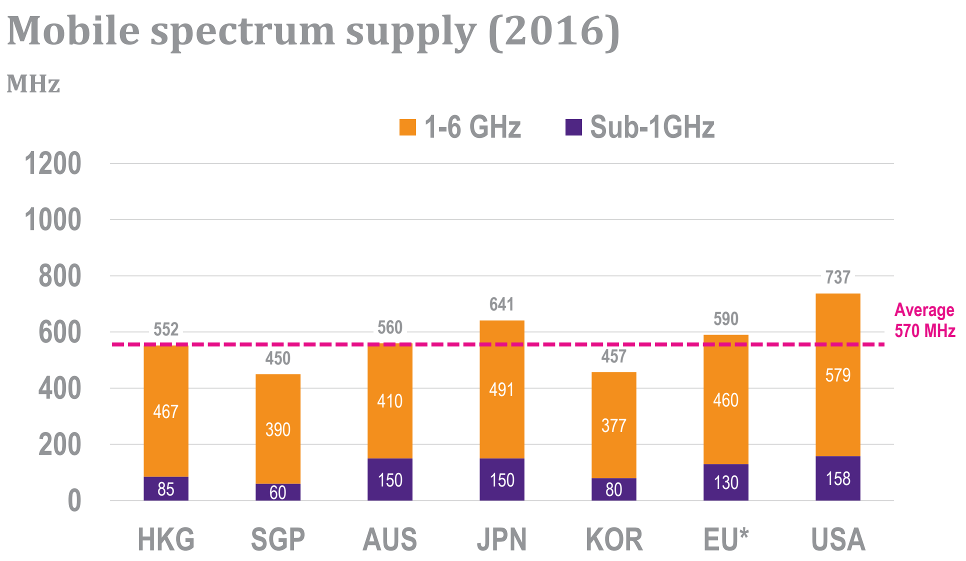
Band (MHz)	850/900	900	1800	2100	2300	2600
HKT	…..	…..	…..	…..	…..	…..
HTCL	…..	…..	…..	…..	…..	…..
CMHK	…..	…..	…..	…..	…..	…..
SMT	…..	…..	…..	…..	…..	…..
GBL	…..	…..	…..	…..	…..	…..

1.2.2 Spectrum supply

The current spectrum assigned for mobile services is as shown in Figure 1-2 below. A total of 552 MHz of spectrum for mobile services has been assigned in Hong Kong as of 22 October 2016.[9] This amount is similar to the likes of Australia, EU and Japan although there is less sub-1 GHz spectrum in Hong Kong compared to those countries which have released digital dividend spectrum (e.g. EU, Australia, US) for mobile services. As regards the availability of the digital dividend spectrum in the 700 MHz band in Hong Kong, the working target for switching off analogue TV services is set at the end of 2020. As such, a clearer picture on the allocation of the 700 MHz band to mobile services will be available at a later time. Since the actual deployment of the 700 MHz band for mobile services in Hong Kong has yet to crystallise, it is uncertain if there will be any additional supply of spectrum within the assessment timeframe of the model (2016 – 2023) and hence, the potential supply of any spectrum in 700 MHz band or any other band has not been taken into account in our model.

[9] The amount of 552 MHz spectrum for mobile services does not include 8 MHz of spectrum (678 – 686 MHz) assigned to Hong Kong Mobile Television Network Limited for the provision of broadcast-type mobile television services, 30 MHz of unpaired spectrum in the 2.3 GHz band assigned in 2012 and deployed for the provision of wireless fixed broadband services, 20 MHz of unpaired spectrum in the 1.9 – 2.2 GHz band assigned in 2001, which was left idle throughout the assignment period of 15 years and was put back to reserve at the end of the assignment term in October 2016, and 9.7 MHz of unpaired spectrum in 2010 – 2019.7 MHz for the provision of public mobile telecommunications services that was put out for auction in February/March 2011 but was left over because of no interested bidder.

Figure 1-2:



Note: * based on assignment of harmonised bands in leading EU countries
Source: Plum Consulting, national regulators

2 The first public consultation jointly conducted by the CA and the Secretary for Commerce and Economic Development (SCED)

The CA and SCED jointly published a consultation paper on the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands upon expiry of the existing assignments for public mobile telecommunications services and spectrum utilisation fee (SUF) on 3 February 2016 (First Consultation Paper).[10] The first consultation set out the current situation and proposed three options for the re-assignment of spectrum in the two bands when the current licences expire in 2020/2021.[11] The consultation closed on 18 May 2016. Subject to the second consultation to be conducted by early 2017, the target of the CA and SCED is to announce the final decision on the spectrum re-assignment by end 2017, in order to give a minimum notice period for the variation or withdrawal of spectrum assignments of three years.

2.1 Overview of the First Consultation Paper

The CA's preliminary proposal set out in the First Consultation Paper takes into account the principles of spectrum management as enshrined in Hong Kong's Radio Spectrum Policy Framework (SPF).[12] In the SPF, the Government states its inclination to adopt a market-based approach to spectrum management in cases where there are likely to be competing demands from providers of non-Government services, unless there are overriding public policy reasons to do otherwise. It is also made clear that there is no legitimate expectation of any right of renewal or RFR upon the expiry of a spectrum assignment under the Telecommunications Ordinance (Cap. 106).

2.1.1 Policy objectives

In the First Consultation Paper, the CA stated that its policy objectives for the spectrum re-assignment process, in addition to the principles as set out in the SPF, are:

(a) Ensuring customer service continuity.

(b) Efficient spectrum utilisation.

(c) Promotion of effective competition.

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10 "*Arrangements for the Frequency Spectrum in the 900 MHz and 1800 MHz Bands upon Expiry of the Existing Assignments for Public Mobile Telecommunications Services and the Spectrum Utilisation Fee"* First Consultation Paper, 3 February 2016. http://www.coms-auth.hk/filemanager/en/content_711/cp20160203_e.pdf

11 The existing assignments of the 198.6 MHz of frequency spectrum in the 900 MHz and 1800 MHz bands are due to expire between 19 November 2020 and 29 September 2021.

12 *Radio Spectrum Policy Framework*, April 2007. http://www.cedb.gov.hk/ccib/eng/legco/pdf/spectrum.pdf

(d) Encouragement of investment and promotion of innovative services.

Ensuring customer service continuity

The CA considered that, given the large amount of spectrum available for 3G and 4G services in other bands (1.9 – 2.2 GHz, 2.3 GHz and 2.5/2.6 GHz bands), the provision of 3G and 4G services would not be an area of concern when it came to re-assigning the 900 MHz and 1800 MHz bands. This analysis included coverage of the MTR and indoor areas. In relation to the MTR, the CA noted that there was full 3G coverage at all MTR stations along all lines while spectrum in 2.3 GHz and 2.5/2.6 GHz bands was being progressively deployed in the existing MTR stations and adjoining tunnels for the provision of 4G services, with priority given to the locations where there were high passenger flows.

However, the provision of 2G services would be relevant for this re-assignment process as all GSM services in Hong Kong were operated using the 900 MHz and 1800 MHz bands and many 2G handsets *only* operated in those frequencies. Significantly, the CA stated that it could not *"preclude the possibility that come 2020/21… there would remain a portion of mobile subscribers who would prefer to access mobile voice services with 2G handsets"* (para 17, the First Consultation Paper). Additionally, Hong Kong had a large number of visitors – 59.3 million in 2015 – and thus there would be a large amount of inbound roaming visitors. Visitors from Mainland China accounted for around 77% of the total amount of visitors to Hong Kong and the Mainland MNOs had not indicated that they would switch off their 2G networks in the coming five years meaning that there could still be a high number of inbound roamers who would use 2G networks in Hong Kong in 2021.

Under the technology neutral approach adopted by the CA, MNOs might decide when to switch off their 2G networks. However, the CA would expect the MNOs to ensure that they would minimise the impact on customers should such a decision be taken.

Efficient spectrum utilisation

The current spectrum assignments in the 900 MHz and 1800 MHz bands are fragmented as shown in Figure 1-1 and such fragmentation reduces spectrum efficiency and limits the technology choice of the MNOs (3G or LTE spectrum is typically based on lots of 2×5 MHz[13]). As part of the re-assignment process, an important consideration would be to allow the consolidation of the current fragmented holdings before re-assignment. This could be done by packaging the spectrum into 2×5 MHz and/or 2×10 MHz frequency lots which would enable MNOs to refarm or aggregate carriers to attain higher spectrum efficiency and service speed post 2020/21.

[13] LTE does support narrower carriers than 5 MHz (1.4 MHz and 3 MHz). While it is possible to support these carriers, their data carrying utility is limited and 5 MHz is seen by most MNOs as the minimum viable bandwidth to support realistic mobile data services, especially video services. Most MNOs now look for carriers of 10 MHz and the opportunity to use carrier aggregation technology to increase the data throughput.

Promotion of effective competition and encouragement of investment and promotion of innovative services

The CA considered the likelihood of the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands to attract a new entrant to the Hong Kong mobile market. Given that these are two core bands for MNOs and that there would unlikely be new spectrum release in Hong Kong in the next five years, the CA considered the re-assignment to be a "*good opportunity to attract new entrants and investments*" (para 21, the First Consultation Paper).

However, the CA concluded that:

"Consistent with the longstanding market-driven approach to regulation of the telecommunications sector, the CA considers that the optimal number of MNOs to meet demand for mobile telecommunications services in Hong Kong should be determined by market forces." (Para 21, the First Consultation Paper)

2.1.2 Re-assignment options

The CA considered three different re-assignment options for the two bands in question as described below.

Option 1: Full-fledged administratively-assigned approach

This approach involved offering the RFR to incumbent spectrum assignees of the 900 MHz and 1800 MHz bands on all their existing spectrum holdings.

The CA considered that there was no public policy reason, let alone any overriding one, supporting this approach. Firstly, the continued provision of legacy 2G services would not require any of the MNOs to keep all of their spectrum in the two bands and therefore there would be no need for all of the MNOs' existing holdings to be renewed. Secondly, the maintenance of the status quo in terms of spectrum holdings would not provide an incentive for MNOs to strive for higher spectrum efficiency. Thirdly, Option 1 was considered to be inconsistent with the CA's duty to ensure efficient allocation and utilisation through consolidating the current holdings *before* the re-assignment. Finally, it was noted that this approach might preclude the possibility of new players entering the market if all of the spectrum would be renewed.

Option 2: Full-fledged market-based approach

Under this approach, no RFR spectrum would be offered to the MNOs and all the spectrum would be made available by auction to the incumbents and potential new players. This approach was considered to address the policy objectives of efficient utilisation of spectrum and the promotion of effective competition, investment and innovation.

However, the CA's main concern with Option 2 was around ensuring customer service continuity of 2G services. The CA noted that 2G services would be maintained by the MNOs as long as it was commercially viable to do so. The concern around 2G service continuity would arise if MNOs had to prematurely switch off their 2G networks in case they failed to secure the spectrum they needed. After an open auction of the whole 900 MHz and 1800 MHz bands an MNO might find itself in either of the following positions:

- Holding no spectrum in both the 900 MHz and 1800 MHz bands. Without this spectrum, the MNO would either need to migrate all 2G customers over to 3G or 4G or adopt alternative methods to serve its remaining 2G customers, for example partnering with another MNO still offering 2G.

- Holding significantly less spectrum in the 900 MHz and 1800 MHz bands. The MNO might decide to allocate all the remaining spectrum in the two bands for 3G and 4G services to maintain mobile data market share and quality of service. In this situation, it might be more cost effective for an MNO to switch off its 2G services significantly earlier than if it had renewed its spectrum holdings.

Either of these two scenarios could hasten the switch off of 2G services before the socially optimal point. Hence the CA put forward the hybrid approach which would guarantee 2G service continuity for consultation.

Option 3: Hybrid approach

The hybrid approach was used by the CA in the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band in 2013. Under this approach each of the MNOs would be offered some RFR spectrum, with the rest of the available spectrum to be auctioned.

The proposed RFR spectrum would be the minimum amount needed for the MNOs to offer 2G services after 2020/21.[14] Although the minimum amount should be less than 2×5 MHz per MNO, the CA proposed to offer a frequency block of 2×5 MHz as the RFR spectrum such that it could be more efficiently refarmed for 3G or 4G in the future. Therefore, the total amount of RFR spectrum was proposed by the CA to be 2×20 MHz, with the remaining 2×80 MHz to be auctioned. MNOs which took up the RFR spectrum would be required to continue to provide 2G services during a three-year transitional period counting from the commencement of the new spectrum assignment term in 2020/21.

[14] The minimum amount of spectrum required to provide extensive 2G coverage is 2×2.4 MHz based on a carrier bandwidth of only 2×0.2 MHz and using a standard re-use factor of 12 for network planning.

Four variants of Option 3 based on different allocation methods of the RFR spectrum were outlined in the First Consultation Paper with the advantages and disadvantages of each one described in Table 2-1.

Table 2-1: Option 3 variants

Variant	Pros	Cons
Option 3A – All 4 RFR slots in the 1800 MHz band	May minimise network reconfiguration as all 4 MNOs hold the spectrum in the 1800 MHz band. Efficient market-based allocation of all the valuable sub-1 GHz spectrum.	May cause issues for the 3 MNOs which have GSM networks designed around 900 MHz.
Option 3B – 3 RFR slots in the 900 MHz band and 1 (CMHK) in the 1800 MHz band	May minimise network reconfiguration as all MNOs would keep the spectrum upon which their GSM network is based.	CMHK would not be assured of access to sub-1 GHz spectrum.
Option 3C – All 4 RFR slots in the 900 MHz band	May minimise network reconfiguration as 3 MNOs keep their best coverage spectrum and 1 MNO gains spectrum with better coverage. All MNOs guaranteed valuable sub-1 GHz spectrum.	CMHK may need to incur additional costs of reconfiguring its network as it does not have 900 MHz at present.
Option 3D – MNOs can choose their RFR spectrum	MNOs are given the flexibility to choose how to minimise their network reconfiguration and maximise their own spectrum efficiency.	–

Source: The First Consultation Paper, 3 February 2016

The First Consultation Paper also covered other details about the proposed spectrum re-assignment including:

- A spectrum cap of 2×45 MHz covering both bands (this would not preclude any MNO renewing or purchasing the same amount of spectrum as it currently holds).
- A spectrum cap in the 900 MHz band of 2×10 MHz which would result in at least three and at most five MNOs holding sub-1 GHz spectrum.
- The end dates of the current 900 MHz licences to be harmonised so that they would all end on 11 January 2021. The 1800 MHz licences would be unchanged to end on 29 September 2021.

- A coverage obligation of 90% of the population using the 900 MHz and 1800 MHz bands individually. The CA considered it likely that the incumbent MNOs would have already met this requirement.

- The spectrum assigned for coverage in country parks and remote areas specified as the designated areas to be administratively re-assigned by the CA for another 15 years with no SUF.

2.2 Submissions from the industry

The submissions from the four incumbent MNOs and China Unicom (Hong Kong) Operations Limited (CUHK) are summarised below. The points covered below mainly relate to the policy considerations and the options for the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands. While the MNOs also touch on issues around SUF, these are not summarised as they fall outside the scope of this Study.

2.2.1 CMHK

The main points of CMHK's submission were:

- There was no overriding public policy reason to favour Option 1, noting that Option 1 was incompatible with the promotion of effective competition, and the encouragement of investment and promotion of innovative services. It could also result in inefficient spectrum allocation and utilisation.

- Under Option 2, there was the risk that MNOs were unable to secure the spectrum they needed which could severely affect 2G service continuity. In the event that MNOs acquired different frequency blocks from their current holdings, there could also be substantial engineering work and unnecessary investment, especially for shared IRS sites.

- CMHK questioned whether the promotion of effective competition and efficient spectrum utilisation would be served by Option 2, citing the 2.3 GHz band case in which entry of a player failed to achieve the desired policy outcomes.

- Option 3 was preferred as it would ensure service continuity and allow MNOs to acquire new spectrum in accordance with their business objectives. The RFR spectrum should comprise 2×5 MHz of the 900 MHz band and 2×10 MHz of the 1800 MHz band for each MNO, with the remaining spectrum available for auction. CMHK noted that it should also have access to spectrum in the 900 MHz band similar to other MNOs as a level playing field would be healthy for the market.

- CMHK noted that indoor radio systems were mainly using the 1800 MHz band and some of the 900 MHz / 1800 MHz spectrum had already been partially refarmed for 4G services and therefore the consideration of RFR spectrum should take account of not only 2G but also 3G and 4G services. The restriction of using the RFR spectrum for 2G services during the 3-year transitional period would not be necessary.

- CMHK agreed with the sub-cap of 20 MHz for the 900 MHz band and was neutral about the overall spectrum cap of 90 MHz.

2.2.2 HKT

In HKT's submission several general points were set out. First, there was a shortfall of spectrum for MNOs in Hong Kong compared to many other countries; the delay in analogue switch-off and hence the release of digital dividend spectrum was a key factor for the spectrum deficit. Second, spectrum trading would be consistent with the CA's policy objectives of promoting efficient allocation and use of spectrum and its implementation should not be delayed. Third, spectrum assignments should have unlimited licence terms to provide certainty for network investment and reduce administration burdens.

With respect to the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands, HKT's main points were:

- It disagreed with the CA's view that 3G and 4G service continuity was unlikely to be an area of concern in assessing the options for the re-assignment exercise; HKT noted that the 900 MHz and 1800 MHz bands were very important in terms of 3G and 4G services and handset compatibility.

- The deployment of the 2.3 GHz and 2.5/2.6 GHz bands in the MTR was slow and it was expected that the 1800 MHz band would still be needed to support 4G services beyond 2020/21.

- The shortfall of spectrum and the intense competition would force the MNOs to use spectrum more efficiently, invest and innovate regardless of the re-assignment options. Excessively high prices paid for spectrum might have a dampening effect on investment and innovation, contrary to OFCA's suggestion that investment and innovation could only be assured if spectrum was auctioned such that MNOs had to pay full market value for their spectrum.

- Encouraging new entry would be better achieved by spectrum trading and making more spectrum available, as opposed to an auction approach.

- Eliminating spectrum fragments and re-organizing the bands into blocks of 2×5 MHz or 2×10 MHz would result in more efficient use of the frequency bands. However, the band plan could be re-organized by OFCA under any of the three spectrum re-assignment methods put forward in the First Consultation Paper.

- Option 1 was the best approach to ensure service continuity and in maintaining a predictable and stable investment environment; it noted that the promotion of efficient spectrum utilisation and promoting effective competition could be achieved regardless of the 3 options.

- Service interruption was a real possibility under Option 2 and this was not restricted to just 2G but also 3G and 4G. HKT made the same point for Option 3.

- For Option 3, the starting point for the consideration of RFR spectrum should be to use the 2/3 approach adopted in the 3G spectrum re-assignment exercise[15] in order to ensure the continuity of 2G, 3G and 4G services. The amount of RFR should be commensurate with an MNO's customer size and its current spectrum holdings. For the 900 MHz band, the RFR spectrum should be 2×5 MHz for each of the 3 incumbent spectrum holders (HKT, HTCL and SMT) with the remaining 2×10 MHz to be auctioned. For the 1800 MHz band, the RFR spectrum should be 2×10 MHz each for CMHK, HTCL and SMT, and 2×30 MHz for HKT, with the remaining 2×15 MHz to be auctioned.

- The requirement to continue provide 2G services for a 3 year period after commencement of the new assignment was contrary to technology neutrality and should be avoided.

- There was no reason to impose any spectrum cap unless there was a substantial competition concern. HKT raised the issue of how the proposed 90 MHz cap would apply to joint ventures between MNOs.

2.2.3 HTCL

The main points of HTCL's submission were:

- The auction arrangement proposed by the CA would put MNOs at risk of losing up to 80% of their current holdings in the 900 MHz and 1800 MHz bands which could have severe adverse impacts on service continuity, effective competition, and encouragement of investment and innovation.

- Spectrum in the 900 MHz and 1800 MHz bands had been extensively refarmed from 2G to 3G and 4G services and was particularly well-suited for indoor coverage; therefore, a loss of this spectrum would affect service continuity and quality of service of 3G and 4G services, especially along MTR lines.

- In a competitive market with scarcity of spectrum, there was no reason to suppose that MNOs were using spectrum inefficiently. The fact that MNOs were refarming spectrum suggested that there were appropriate incentives to ensure efficient use of spectrum. An auction did not enhance spectrum efficiency.

[15] As regards the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band, RFR spectrum of 2×10 MHz was assigned to each incumbent 3G MNO out of the 2×15 MHz held by each incumbent 3G MNO.

- HTCL preferred Option 1, arguing that it would provide the necessary certainty to services and business continuity and allow existing MNOs to continue to invest in advanced technology. HTCL agreed with the consolidation and elimination of fragmented spectrum before the re-assignment.

- If Option 1 were not adopted, HTCL proposed an alternative Option 4 in which the RFR spectrum for each of the four MNOs would consist of 2×5 MHz of the 900 MHz band and 2×15 MHz of the 1800 MHz band. The remaining spectrum, 2×5 MHz of the 900 MHz band and 2×15 MHz of the 1800 MHz band would be subject to auction.

- The CA's proposed three-year requirement for MNOs which had taken up the RFR spectrum to continue to provide 2G services was inconsistent with the technology-neutral approach; the requirement was not necessary and MNOs should be left free to meet market demand and not be prevented from encouraging customers to migrate to 3G or 4G services.

2.2.4 SMT

The main points of SMT's submission were:

- Option 1 would not be viable as this would preserve the current asymmetry of spectrum holdings among MNOs and not meet the CA's identified objectives of efficient spectrum utilisation, promoting effective competition and encouragement of investment and promotion of innovative services. Option 3 could meet the CA's identified objectives but mobile service continuity would still be an issue if only 2×5 MHz of either the 900 MHz or 1800 MHz band was set aside as RFR spectrum. Option 2 would not ensure service continuity.

- The issue of service continuity was not just concerned with 2G voice services but also 3G and 4G data service as most of the 900 MHz and 1800 MHz bands had been deployed for 3G and 4G services. A full-fledged auction under Option 2 would have a far greater impact on mobile data services which was of far more concern than to customers than 2G voice services.

- Service continuity of mobile data services in the MTR was a key concern. SMT noted that 4G services in the MTR depend primarily on the 900 MHz and 1800 MHz bands and this would be substantially affected if existing MNOs were unable to obtain at least 2×15 MHz in these bands. Spectrum in the 2.1 GHz band was insufficient to cope with the huge demand in the MTR and could lead to overloading of the 3G network. Furthermore, the deployment of the 2.3 GHz and 2.5/2.6 GHz bands in 8 stations was due to be completed in mid-2018 and it would be unlikely that full coverage in all MTR stations would be achieved by 2020. Lastly, if the new assignments in the 900 MHz and 1800 MHz bands were different from current frequencies supported in the existing points of interconnection (POIs) in the MTR and common antenna systems, then a change in POIs would be needed which requires substantial lead time and could cause service disruption.

- For Option 3, the proposed RFR spectrum of 2×5 MHz would be insufficient to ensure mobile data service continuity, particularly in the MTR and common antenna systems. Instead the RFR spectrum should comprise 2×10 MHz for the four MNOs currently holding spectrum in the 1800 MHz band and 2×5 MHz for the three MNOs currently holding spectrum in the 900 MHz band.

- The amount of RFR spectrum should not be proportional to the amount of spectrum currently held as this would in effect preserve the status quo of asymmetric holdings which was not in accordance with the policy aims of the SPF.

- The proposed requirement for incumbents who had taken up the RFR spectrum to continue the provision of 2G services for 3 years from 2020 was against the principle of technology neutrality and efficient use of spectrum; the continuation of 2G services beyond 2020 should be a commercial decision for the MNOs.

- In terms of spectrum caps, SMT suggested that the overall cap should be 80 MHz (2×40 MHz) instead of 90 MHz as proposed by the CA. SMT agreed on the 20 MHz sub-cap for the 900 MHz band.

2.2.5 CUHK

CUHK is a Mobile Virtual Network Operator (MVNO) in Hong Kong. In its short submission CUHK suggested that there should be active migration of existing 2G users to 3G and 4G to enable the withdrawal of all frequency spectrum in the 900 MHz and 1800 MHz bands for re-assignment by auction (i.e. Option 2). CUHK also indicated that it was planning to actively participate in the auction taking into account the development of the market and its company position.

2.2.6 MNOs' preferences on re-assignment options

In summary, none of the incumbent MNOs were in favour of Option 2 as this would lead to interruptions of 2G, 3G and 4G services. HKT and HTCL favoured Option 1 and were open to Option 3, while CMHK and SMT preferred Option 3. Yet all indicated that the CA's proposed RFR of 2×5 MHz was insufficient. The view of each MNO relating to the portion of RFR spectrum in the two bands is shown in Table 2-2.

Table 2-2: MNOs' view on RFR Spectrum

MNO	900 MHz band	1800 MHz band	Spectrum for auction
CMHK	2×5 MHz (all 4 MNOs)	2×10 MHz (all 4 MNOs)	80 MHz – 2×5 MHz (900 MHz band); 2×35 (1800 MHz band)
HKT	2×5 MHz (HKT, HTCL, SMT)	2×30 MHz (HKT); 2×10 MHz (CMHK, HTCL, SMT)	50 MHz – 2×10 MHz (900 MHz band); 2×15 (1800 MHz band)

MNO	900 MHz band	1800 MHz band	Spectrum for auction
HTCL	2×5 MHz (all 4 MNOs)	2×15 MHz (all 4 MNOs)	40 MHz – 2×5 MHz (900 MHz band); 2×15 (1800 MHz band)
SMT	2×5 MHz (HKT, HTCL, SMT)	2×10 MHz (all 4 MNOs)	90 MHz – 2×10 MHz (900 MHz band); 2×35 (1800 MHz band)

3 Assessment model

3.1 Purpose and objectives

The Study provides an independent and objective quantitative assessment of the impacts on service quality arising from the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands. An assessment of this nature is complex and it needs to take into account of a number of factors, including:

- Network capacity and capacity expansion
- Traffic demand and demand growth
- Availability and practicality of suitable mitigating measures
- Impact of technology advancement
- Extent of long term demand for 2G or 3G connectivity.[16]

The purpose of the assessment model is to compare the potential impact on service quality for a set of demand and spectrum scenarios and where service quality degrades below a threshold level the mitigating measures that might be employed and what the outcomes of these might be. A numerical measuring indicator is required for quantifying service quality as it is hard to describe precisely what the impact on service quality for a given network user will be. The measuring indicator presented in this report is called the DCO.[17] It should be noted that the assessment model is a tool that provides a representative view of network performance based on data from the MNOs and a set of general assumptions and it is not a network planning tool that precisely mirrors the actual operation of the MNO's networks and their performance. While the assessment model provides a good representation of network behaviour across a network of many sites/sectors, its output is less useful and potentially misleading if the application of the model is made too granular (e.g. looking at a single or small number of network sectors).

3.2 Plum's approach

Plum's approach to conducting the assessment has involved a combination of market forecasting and technical modelling. The assessment model has been developed using a spreadsheet based model. It analyses the impact on network infrastructure requirements under various technology evolution and spectrum availability scenarios; for all MNOs and each

16 For example, the long term demand to support machine-to-machine (M2M) applications, circuit switched voice fall back or roaming.

17 DCO is the same metric presented in the technical study for the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band. See Section 3.6.

individual MNO; for territory-wide network and for high traffic areas. The high traffic areas (the busiest 20% of sites) in terms of mobile network traffic carried are considered discretely to analyse any performance impact on the busiest sites of networks. It is assumed that the busiest 20% of sites carry 60% of network traffic. This ratio is derived from other Plum studies and discussion with equipment vendors. It is consistent with feedback from the MNOs. When considering the highest loaded part of the network a trade-off must be made between selecting only the highest loaded cells, which may experience congestion on a regular basis, and parts of the network where congestion is less frequently experienced. In practice this trade off tends to occur in the region of the busiest 15-20% of sites. Given the user density of Hong Kong and the high number of sites/sectors in busy areas, the busiest 20% of sites have been chosen.

The assessment model estimates the network capacity based on the existing network infrastructure of each MNO. It then compares this with busy hour traffic demand. This process is carried out for a number of scenarios in which the outcomes of spectrum assignments for the MNOs are varied.

A description of the assessment model is at Appendix B. The modelling approach has been discussed with the MNOs which generally agreed with the approach taken.

There are three parts in the assessment model:

- **Inputs** for infrastructure, spectrum, subscribers, traffic demand, spectrum utilisation, spectrum efficiency, maximum cell loading, refarming, Wi-Fi offload, the spectrum retained for 2G services and whether a new entrant is to be considered. The input module also allows a number of selections to be made for each model run including analysis of the territory wide network or high traffic areas and the type of mobile technology being considered.

- **Internal modules** which carry out the calculation function of the assessment model. The internal modules generate the data to be handled by the output modules.

- **Output modules** which produce both tabular and graphical representations of the assessment model outputs. The key outputs are demand and capacity values by MNO and technology, from which the DCO figures will be evaluated.

The modelling period covers a time span of eight years from 2016 to 2023. This period is chosen because it presents a view of the current situation as of 2016 and how the situation would change over the period. The re-assignment is scheduled to take place in 2021 and the extension to 2023 provides some indication on the impact of the changes in spectrum holdings post re-assignment. An extension beyond 2023 may not be relevant as more spectrum and other technology such as 5G could be made available to the MNOs by then. Table 3-1 lists the main input assumptions for the assessment model.

Table 3-1: Summary of main input assumptions for the assessment model

Parameter	Value used	Sources / notes
Subscribers (2G, 3G, 4G)	Actual and forecast values	Source: MNO data Where unavailable, Plum assumptions are made based on discussions with MNOs and observed trends from other MNOs' data
Voice traffic (minutes) (2G, 3G)	Actual and forecast values	Source: MNO data Voice traffic in minutes (2G, 3G) are converted into equivalent data stream for calculation in the assessment model. Voice over LTE (VoLTE) traffic is included in the LTE data traffic Where unavailable, Plum assumptions are made based on discussions with MNOs and observed trends from other MNOs' data
Data traffic (2G, 3G, 4G)	Actual and forecast values	Source: MNO data, Cisco Where unavailable, Plum assumptions are made based on discussions with MNOs, Cisco forecasts and observed trends from other MNOs' data (See Appendix A.1)
Proportion of traffic in busy hour (2G, 3G, 4G)	Between 5.8% and 8.1%	Source: MNO data The values vary by MNO and by technology
2G spectrum efficiency (bits/sec/Hz)	0.05 bits/sec/Hz	Source: Plum based on industry agreed value It is based on frequency reuse of 12 and assumed to be constant from 2016 – 2023
3G spectrum efficiency (bits/sec/Hz)	0.4 bits/sec/Hz	Source: Plum It is based on industry agreed value and assumed to be constant from 2016 – 2023
4G spectrum efficiency (bits/sec/Hz)	1.3 bits/sec/Hz (2016) rising to 1.6 bits/sec/Hz (2023)	Source: Plum It is based on industry agreed values on achieved efficiency rates in practice
Base stations – indoor and outdoor (2G, 3G, 4G)	Actual and forecast values	Source: MNO data Where unavailable, Plum assumptions are made based on discussions with MNOs and observed trends from other MNOs' data
Sectors per site	Between 1 and 6	Source: MNO data

3.3 Inputs from stakeholders

As part of the Study, Plum has conducted an extensive information gathering and consultation process with each of the MNOs and the MTRC. A summary of the data items requested from the parties is at Appendix A. The engagement with the MNOs involved:

- A data gathering exercise – a questionnaire and an excel data request template were sent to the MNOs in April 2016; responses from all four MNOs were received in May 2016. A subsequent round of data gathering was conducted in July 2016 to gather additional information from the MTRC.

- Three rounds of meetings in Hong Kong – the first round in April 2016 covered the general assessment approach, the key considerations in the Study and the inputs and outputs of the assessment model; the second round in June 2016 involved clarification on the data provided by the MNOs and an update on the assessment model; and the third round in September 2016 briefed the MNOs on the preliminary assessment results and key assumptions for the assessment model.

All four MNOs were cooperative throughout the engagement process. The views expressed during the three meetings with Plum reflect the MNOs' consultation responses with further elaboration of their main concerns, namely the importance of the 900 MHz and 1800 MHz bands to all mobile services and not just 2G, the difficulties of implementing frequency changes to the legacy IRS and the protracted negotiations and slow upgrade programme of the MTRC. Furthermore, Plum met with a MVNO which gave submission in response to the first consultation to solicit its views in relation to the Study. The notes of the three sets of meetings with the MNOs and the MVNO have been summarised in separate reports for OFCA.

In addition, Plum met with the MTRC in April 2016 to gain a better understanding of the configuration of the IRS at MTR premises, the frequency bands supported, the upgrade programme and the deployment of Wi-Fi in MTR stations. In a subsequent teleconference in June 2016, the MTRC provided clarification on the timescales and procedures for the upgrade programme. A further meeting with the MTRC was held in September 2016.

The MNOs were given opportunities to comment on the model assumptions and preliminary assessment results. Their comments have been taken into account when finalising the model. A summary of the feedback of the MNOs and the MTRC is provided in Appendix E.

3.3.1 Quality of data provided

In terms of the data gathering, Plum has requested information from each MNO on network traffic, existing infrastructure and coverage, utilisation of existing spectrum and new service and technology developments. Future projections have also been requested for network traffic by technology (every year up to 2023) and for infrastructure and spectrum utilisation in 2020.

While all four MNOs provided their responses based on the data request template supplied by Plum, there were a number of issues with their responses, in particular:

- [✂….]'s network traffic projection only covered up to 2021 and was not disaggregated by technology; [✂….] also did not provide data on base stations, sectorisation and frequency deployments in 2020.
- [✂….] had differing views on the rate of mobile traffic growth.
- [✂….] only provided actual data for 2015 and March 2016, but not any forecast for future years.

Where possible, Plum has sought to gather the missing information through the discussions with the MNOs during the meetings in June 2016.

In order to address the data deficiencies, a number of assumptions have to be made for the input assumptions to the model as discussed in following sections.

3.4 Projection of network traffic demand

3.4.1 Voice traffic

The assessment model considers the impact of voice traffic across all technologies (2G, 3G and 4G). It includes circuit switched voice (2G, 3G) and VoLTE (4G). Circuit switched voice is translated from minutes into an equivalent data stream for the purpose of the assessment model. This is done by applying a voice codec bit rate to the amount of voice traffic carried by 2G, 3G and 4G networks. Voice traffic volumes are based on information received from the MNOs.

3.4.2 Data traffic

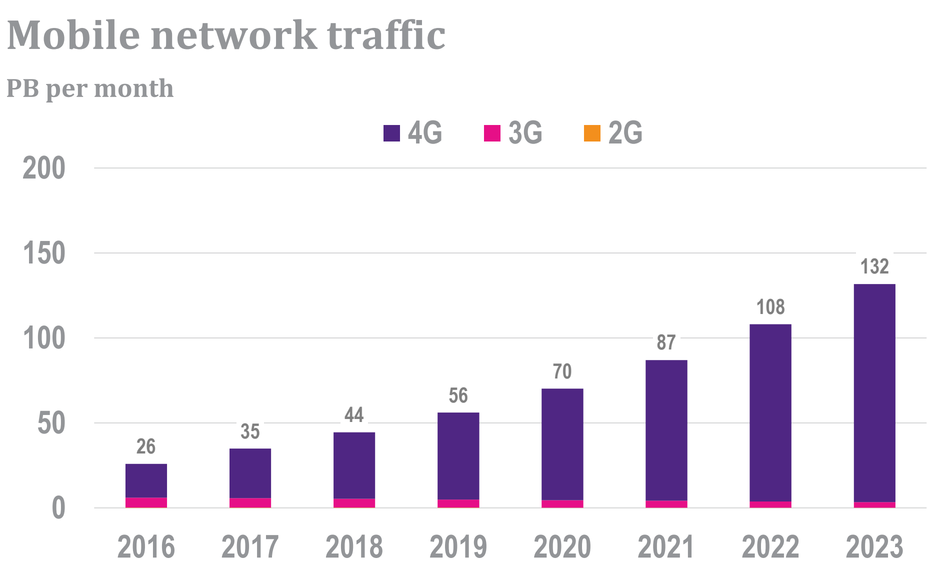
The assessment model considers the impact of data traffic across all technologies (2G, 3G and 4G). Data traffic volumes are based on information received from the MNOs where possible. The MNOs were requested to provide traffic demand forecasts to Plum for 2G, 3G and 4G traffic. Three of the MNOs complied with this request ([✂….] has only provided historical data of traffic in 2015 and 2016 but not any forecast for future years) though the data provided was not complete in some instances. However, there was a wide variation between the lowest and highest MNO forecasts.

In some cases, after discussion with the MNOs, Plum modified data traffic demand forecasts to provide a more plausible forecast. Plum cross checked the MNO forecasts against its own forecasts and a forecast derived from the Cisco Visual Networking Index (VNI) for Japan and

Korea.[18] Plum's opinion was that the highest of the MNO forecasts was excessively high and that it appeared to be based on a constant growth rate over the forecast period based on the regional Asia Pacific growth rate [✂….]. This was not considered a credible approach as the data traffic growth rate would be expected to reduce over time, especially in a mature market like Hong Kong where growth in subscribers is slowing. This forecast was adjusted downwards following a discussion with the MNO. For the MNO that did not provide a forecast, its traffic forecast was derived by considering the forecast of other MNOs having the nearest volume of historical data traffic.

Based on the inputs provided by the MNOs together with the modifications discussed in Appendix A.1. Plum has derived a forecast set for use in the assessment model. Figure 3-1 shows the total data traffic in petabyte (PB) per month[19] for Hong Kong by technology (including voice traffic translated into equivalent data stream). The majority of mobile network traffic is 4G (77% in 2016, growing to 97% in 2023) while 3G traffic is forecast to decline from 22% in 2016 to 2% of total traffic in 2023 as the majority of customers migrate to 4G. Traffic on 2G comprises just 0.6% of total traffic in 2016 and this is expected to decline to 0.04% by 2023; which is line with the MNOs' expectations of 2G. Overall, mobile data traffic is projected to grow on average by 26% per annum between 2016 and 2023.

Figure 3-1:



Source: Plum Consulting, MNO data

Based on the traffic and subscriber numbers provided by the MNOs and the modification to forecasts made by Plum, the average monthly traffic per subscriber will increase from the

[18] Cisco VNI does not provide a dedicated forecast for Hong Kong.

[19] 1 PB equals to one thousand terabytes (TB), or one million gigabytes (GB) is used in the calculation.

current average of 2 GB to 9 GB in 2023. Table 3-2 shows the data traffic (including voice traffic translated into equivalent data stream) per subscriber in 2016 and the forecast for 2023.

Table 3-2: Monthly data traffic (including voice traffic translated into equivalent data stream) per subscriber in 2016 and 2023

MNO	2016	2023
All (average)	2 GB	9 GB
MNO1	….	….
MNO2	….	….
MNO3	….	….
MNO4	….	….

3.4.3 Additional aspects on traffic

The assessment model considers both downlink and uplink data traffic. In practice the downlink dominates the assessment and hence is used for the presentation of results. The ratio of downlink to uplink is based on Plum's analysis and inputs from MNOs.

Total traffic is the summation of data traffic and the data stream derived from the volume of voice traffic. This is then converted into a busy hour traffic using the factor for percentage of busy hour traffic derived from MNO inputs. Based on inputs from MNOs, the value of this factor lies in the range 5.8% to 8.1% and varies by technology. [✂….]

3.5 Network capacity model

3.5.1 Infrastructure

The assessment model considers different classes of infrastructure – outdoor (macro and micro cell), indoor and the MTR system – in terms of number of cell sites and sectors. It also considers 2G, 3G and 4G technologies. Inputs on the amount of infrastructure are based on information received from the MNOs. The MNOs provided data on both outdoor and indoor networks. Growth in infrastructure over the modelling period is based on inputs from the MNOs supplemented with input from Plum where required. The growth in infrastructure is expected to come from the building of new outdoor macro sites, the addition of more sectors to existing sites and the deployment of 3G/4G small cells.

So far, the deployment of small cell infrastructure in Hong Kong is still picking up momentum. The MNOs advised that to date there have been a number of barriers such as gaining access to sites and planning regulation that create logistical and cost difficulties. We understand that these issues are being addressed by OFCA and other authorities and that over time barriers to small cell deployment could be lowered. This will make their deployment a more practical proposition for increasing network capacity.

For macro sites there are limits to the increase in sectorisation that can be achieved in practice, particularly where there is a dense cell architecture and inter-site distances are small (e.g. less than a few hundred metres). While up to 6 sectors can be supported at sites most MNOs are operating their networks with an average of 3-4 sectors. Adding additional sectors will improve the capacity but there are limits to how far this strategy can be pursued. If the sector architecture becomes too dense there is the potential for high levels of intra and inter-cell interference[20], which works against the capacity increase that additional sectors could deliver.

In the assessment model Plum has taken into account the views of the MNOs in terms of what can practically be achieved and the maximum increase in sectors foreseen has been set at 10%.

3.5.2 Technology evolution

Technology evolution is considered from two perspectives:

- The refarming of spectrum from 2G or 3G to 4G. Refarming assumptions are based on a combination of MNOs' input and Plum's analysis.

- The increase in average spectrum efficiency for 4G equipment over time taking into account the evolution of advanced mobile technologies such as Multi-input Multi-output (MIMO). In the period considered by the assessment model this is assumed to increase from 1.3 to 1.6 bits/sec/Hz (2016 to 2023).[21]

- The spectrum efficiency assumptions for 2G and 3G services are kept constant throughout the modelling period at 0.05 bits/sec/Hz[22] and 0.4 bits/sec/Hz[23] for 2G and 3G respectively.

The theoretical headline numbers for spectrum efficiency for each 3GPP release are higher than those stated here. In practice, these numbers are rarely achieved in real networks when interference, usage and clutter considerations are taken into account. The spectrum efficiency assumptions used in the assessment were discussed with the MNOs.

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[20] Excessive re-use of frequencies can lead to increase in co-channel interference from neighbouring cells (inter-cell), which can affect the quality of both voice and data services.

[21] These are industry-consensus values from vendors and MNOs and have been used by Plum for network modelling in numerous other studies.

[22] This is based on a frequency reuse factor of 12.

[23] The 3G spectrum efficiency measure is derived from the average of spectrum efficiencies of UMTS and HSPA technologies.

Spectrum efficiency has been considered in other studies including that by Real Wireless for the Office of Communications (Ofcom).[24] It showed that a wide range of spectrum efficiency outcomes are possible depending on network and technology configuration. It is stated that the expected average spectrum efficiency of LTE Release 8 is expected to be 1.5 bits/sec/Hz. In Peter Rysavy's IEEE paper[25], it is stated that LTE in a typical 2×2 MIMO configuration has a spectrum efficiency of 1.4 bits/sec/Hz. These values are consistent with the values Plum used in the assessment model (1.3 – 1.6 bits/sec/Hz).

MNOs will be expected to implement new technology which increases the efficiency of networks as it becomes available (e.g. new 3GPP releases). New devices coming to market will also be picking up these advances. Hence spectrum efficiency will keep increasing over the assessment period.

The technology evolution assumptions are most robust for the main macro and small cell network of the MNOs. Legacy IRS are more difficult to upgrade and the evolution path for these systems is not under the control of the MNOs. Similar considerations to IRS also apply to the upgrade of network capacity at MTR premises.

3.5.3 Spectrum utilisation

Hong Kong is a densely populated environment with a high level of traffic demand per square kilometre. A dense network is required to support the traffic demand and in many instances 3G and 4G sectors use all of the spectrum available to do this. Unlike 2G systems, 3G and 4G systems can theoretically operate with a frequency reuse factor of 1 such that all spectrum available are deployed in all 3G and 4G sectors.

In practice, there are a number of sites/sectors where not all spectrum is deployed and this is considered in the assessment model by use of a spectrum utilisation factor to correctly represent the amount of spectrum actually deployed at sites.

Most frequency spectrum currently deployed in Hong Kong is Frequency Division Duplexing (FDD), except for the 2.3 GHz band with Time Division Duplexing (TDD) deployed. For this band it is assumed that the downlink to uplink ratio for traffic is 3:1.

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[24] Report for Ofcom, 4G capacity gains, January 2011 http://stakeholders.ofcom.org.uk/binaries/research/technology-research/2011/4g/4GCapacityGainsFinalReport.pdf

[25] Challenges and considerations in defining spectrum efficiency, Peter Rysavy

3.5.4 Spectrum deployed

Due to the higher spectrum efficiency of 4G technology, a key assumption in the spectrum deployment assumptions is that MNOs will prefer to refarm their 2G and 3G spectrum over to 4G as soon as practicable, so long as refarming does not impact the service quality of 2G and 3G services. The timing and amount of spectrum deployed for 4G services are based on discussions with the MNOs during the meetings in April, June and September 2016. Further assumptions include:

- In the base case (status quo), all MNOs will keep their existing frequency spectrum in the 900 MHz and 1800 MHz bands as it is. We assume the amount of spectrum deployed with 2G technology pre- and post-re-assignment are unchanged. For all other scenarios, it is assumed that the MNOs would keep the optimal amounts needed to support 2G services and refarm the rest in 2021. Based on the discussions with the MNOs, [✂….] will retain [✂….] MHz for 2G and [✂….] will retain [✂….] MHz. These are adopted in the assessment model.

- For spectrum in the 1.9 – 2.2 GHz band, it is assumed that all MNOs would seek to refarm this spectrum for 4G services where practicable but retain appropriate amounts to cater for 3G customers.[26] Therefore the timing of refarming and the amount of spectrum refarmed may differ by MNO depending on the traffic on their 3G networks.

  – [✂….]

  – [✂….]

- [✂….]

- [✂….]

- As discussed in Section 1.2.2, it is assumed that the 700 MHz band is not available by the time of the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands in 2021 as the working target for switching off analogue television services is by the end of 2020 subject to a review of the target date to be conducted in 2017-18.

- HKT's spectrum in the 850 MHz band which is currently deployed for CDMA2000 and will expire in 2023 is not considered in the assessment model.

Table 3-3 shows the spectrum holdings by technology for all MNOs from 2016 to 2023 in the base case scenario where all the MNOs retain their current spectrum assignments in the 900 MHz and 1800 MHz bands. It is assumed that, for all MNOs, the amount of frequency spectrum in the 900 MHz and 1800 MHz bands currently deployed for 2G services would

[26] This was the general consensus among the MNOs during the discussions in April 2016 and June 2016. [✂….] mentioned that it was seeking to refarm [✂….] MHz or [✂….] MHz of 1.9 – 2.2 GHz for 4G before 2020.

remain unchanged, whereas spectrum in other frequency bands would be refarmed for 4G services where practicable but with appropriate amount of spectrum retained for 3G services.

Table 3-3: Spectrum holdings by technology – all bands, incumbent MNOs [Base case]

	2016	2017	2018	2019	2020	2021	2022	2023
2G	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8
3G	2 x 69.5	2 x 69.5	2 x 69.5	2 x 69.5	2 x 69.5	2 x 30	2 x 30	2 x 30
4G (FDD)	2 x 143	2 x 143	2 x 143	2 x 143	2 x 143	2 x 182.5	2 x 182.5	2 x 182.5
4G (TDD)	60	60	60	60	60	60	60	60

Table 3-4 shows the spectrum holdings by technology for all MNOs from 2016 to 2023 in the other scenarios without a new entrant where the MNOs retain a total of 2×10.4 MHz spectrum for 2G services and refarm the rest of the spectrum in other frequency bands for 4G services where practicable.

Table 3-4: Spectrum holdings by technology – all bands, incumbent MNOs [Retaining 2×10.4 MHz for all MNOs for 2G services without new entrant]

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 26.8	2 x 10.4	2 x 10.4	2 x 10.4
3G	2 x 69.5	2 x 69.5	2 x 69.5	2 x 69.5	2 x 69.5	2 x 30	2 x 30	2 x 30
4G (FDD)	2 x 143	2 x 143	2 x 143	2 x 143	2 x 143	2 x 199.6	2 x 199.6	2 x 199.6
4G (TDD)	60	60	60	60	60	60	60	60

Table 3-5 shows the spectrum holdings by technology for each MNO from 2016 to 2023 in the base case scenario. The full breakdown on the details of spectrum deployed by band for each MNO in each of the scenarios considered in this Study is provided in Appendix C.

Table 3-5: Spectrum holdings by technology – all bands [Base case scenario]

	2016	2017	2018	2019	2020	2021	2022	2023
MNO1								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
MNO2								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..
MNO3								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..
MNO4								
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

Notes to Tables 3-3 to 3-5:

(1) 2G holdings based on 900 MHz and 1800 MHz bands where applicable;

(2) 3G holdings based on 850 MHz, 900 MHz and 1.9 – 2.2 GHz bands where applicable;

(3) 4G holdings based on 850 MHz, 900 MHz, 1800 MHz, 1.9 – 2.2 GHz, 2.3 GHz and 2.5/2.6 GHz bands where applicable;

(4) Spectrum holdings for each MNO have been rounded up to the nearest integer value for the purpose of modelling calculations.

3.5.5 Calculation of network capacity

For each technology type, capacity is calculated by multiplying the number of sectors by the spectrum deployed and then multiplying by the relevant spectrum efficiency and spectrum utilisation. The output of this calculation provides the amount of data throughput per second that the networks of the incumbent MNOs support. The model used the same assumption for deriving the capacity provided by the spectrum in the 900 MHz and 1800 MHz bands. This assumption is made as the frequency at which the cell operates is largely independent of the coding and modulation, which determines data throughput.

3.6 DCO

DCO was the indicator used in the previous study on the re-assignment of the frequency spectrum in the 1.9 – 2.2 GHz band in Hong Kong.[27] The DCO shows the percentage of demand unable to be met by the network design capacity and is calculated as follows:

$$DCO = maximum\ of\ zero\ and\ (demand - threshold \times capacity) / demand.$$

The DCO was extensively discussed in the 3G spectrum re-assignment exercise and results of this Study will also be presented in the form of DCO for sake of consistency.

As the traffic demand increases, the service quality offered by the network will decrease. This is the result of network loading and the decreased ability of the network to allocate resources to existing and new users. For the purpose of the calculation of DCO, the network loading threshold is set as 80% of the total network capacity. That means a zero DCO calculated for a particular scenario would indicate that the traffic demand is less than 80% of the total network capacity. In contrast, a positive DCO will indicate excessive traffic demand beyond 80% of the total network capacity, which implies the possibility of service quality issues[28].

The 80% threshold is based on information from equipment vendors, discussion with the MNOs and other studies performed by Plum.[29]

3.7 Scenarios used in the assessment model

The assessment model can support analysis of multiple market and spectrum scenarios.

A number of market scenarios are initially considered reflecting different evolutions of the share of traffic between MNOs over time. These are eventually narrowed down to one market scenario based on traffic shares derived using the traffic forecasts from the MNOs. This is considered to be the most likely evolution of traffic shares.

The spectrum scenarios reflect different distributions of spectrum between the MNOs depending on the outcome of the auction. The spectrum scenarios considered are as follows:

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[27] See Network Strategies. Reassigning the spectrum in the 1.9 – 2.2 GHz band. Final report for OFCA. 29 August 2013. http://www.ofca.gov.hk/filemanager/ofca/common/reports/consultancy/cr_201311_01_en.pdf

[28] The 80% network capacity is a level at which there is a reasonable expectation of minimal or no service quality issues. However, on a localised basis there could still possibly be instances of congestion on sectors even when the DCO is 0%.

[29] In the consultancy report for reassigning the frequency spectrum in the 1.9 – 2.2 GHz band, the network loading threshold was set at 75%. More recent HSPA and LTE technologies, with improved scheduling and other features, can work above this loading level and hence 80% is an appropriate threshold level. Equipment vendors suggest that the maximum loading on LTE networks before significant issues occur can be as high as 85% if scheduling and inter sector/cell interference is well managed.

Table 3-7: Spectrum scenarios used in assessment

Scenarios	Notes
1. Base case (status quo) – No change in current assignments	All MNOs are assumed to retain their current holdings in the frequency spectrum in the 900 MHz and 1800 MHz bands. This status quo scenario is considered as the counterfactual or base case.
2. Spectrum re-assigned in current proportions but defragmented	All MNOs retain current amounts of spectrum but the holdings are defragmented to allow more efficient spectrum use.
3. Spectrum re-shuffling among incumbent MNOs involving 2×20 MHz of spectrum in total	The MNOs end up with different amounts of spectrum post re-assignment. Under this scenario, two MNOs would lose some of their existing spectrum holdings to the other two MNOs. See Table 3-8 below.
4. Spectrum re-shuffling among incumbent MNOs involving 2×15 MHz of spectrum in total	The MNOs end up with different amounts of spectrum post re-assignment. Under this scenario, [✂….] would lose some of its existing spectrum holding to two other MNOs. See Table 3-8 below.
5. Spectrum assignments reflect MNO market share	The MNOs acquire amounts of spectrum which are in line with their share of mobile traffic. The rationale is that spectrum acquisition is driven primarily by the traffic demand situation at the time of re-assignment.
6A to 6E. A new entrant acquires spectrum	In these scenarios, a new entrant acquires some spectrum in the auction, reducing the total spectrum holdings of the four incumbent MNOs to varying degrees. Five different cases are considered. See Table 3-8 below.

3.7.1 Scenarios with a new entrant

The assessment model considers the possibility of a new entrant. In the course of the Study, Plum met with a potential new entrant (CUHK) who already provides mobile services as an MVNO[30] in Hong Kong. It is unclear whether there will be a new entrant when the auction takes place but entry is not ruled out. Plum has therefore considered a number of options for a new entrant to acquire frequency spectrum in the 900 MHz and 1800 MHz bands currently held by the incumbent MNOs. Having considered the current market situation, inputs from MNOs/MVNO and following discussion with OFCA, the scenarios to be assessed are narrowed down to those shown in Table 3-8 (scenarios 6A to 6E).

It should be noted that the 900 MHz and 1800 MHz bands are attractive for MNOs – especially the 1800 MHz band as this is currently the core LTE band in most territories.[31] When any part of the bands are put out for auction, the expected competition would make it unlikely that a

30 CUHK is a MVNO with its own core network and home location register in Hong Kong.

31 The 1800 MHz band is the most widely supported LTE band. According to the Global Mobile Suppliers Association (GSA), there are 5,614 LTE devices as of June 2016; out of these, more than half (3,227) support the 1800 MHz band. Source: GSA Report: Status of the LTE Ecosystem, 24 June 2016, available at http://gsacom.com/.

new entrant can acquire more than 2×20 MHz of spectrum across the two bands (i.e. one-fifth of the concerned spectrum). Further, there is low probability that any spectrum acquired by a new entrant will come from one MNO. Rather it is more likely to come from several of the MNOs (e.g. in 2×5 MHz, 2×10 MHz or 2×15 MHz blocks).

The detailed breakdown of spectrum holdings by band for each MNO under the analysed scenarios is provided in Appendix C.

Table 3-8: Post re-assignment spectrum distribution by scenario (900 MHz and 1800 MHz bands)

Spectrum scenario	MNO1	MNO2	MNO3	MNO4	New entrant
1. Base case (status quo) – no change in current assignments	…..	…..	…..	…..	NA
2. Spectrum re-assigned in current proportions but defragmented	…..	…..	…..	…..	NA
3. Spectrum reshuffling among incumbent MNOs involving 2×20 MHz of spectrum in total	…..	…..	…..	…..	NA
4. Spectrum reshuffling among incumbent MNOs involving 2×15 MHz of spectrum in total	…..	…..	…..	…..	NA
5. Spectrum assignments reflect MNO market share	…..	…..	…..	…..	NA
6A. New entrant acquires 2×20 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]	…..	…..	…..	…..	…..
6B. New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]	…..	…..	…..	…..	…..
6C. New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]	…..	…..	…..	…..	…..
6D. New entrant acquires 2×10 MHz currently held by [✂….]	…..	…..	…..	…..	…..
6E. New entrant acquires 2×10 MHz currently held by [✂….], 2×5 MHz currently held by [✂….], 2×5 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]	…..	…..	…..	…..	…..

3.8 Use of mitigating measures

Mitigating measures will be applied when the DCO indicates service quality may likely be affected in the model assessment. In such cases there is demand in excess of 80% of the network capacity available resulting in degraded service quality. In the assessment, we consider three ways to mitigate any degraded service quality, including:

- Expansion of network capacity
- Offloading traffic onto another network (e.g. Wi-Fi infrastructure)
- Migrating customers to technologies with higher spectrum efficiency (such as 4G) and to refarm the spectrum to higher efficient technologies (e.g. 3G to 4G).

It should be noted that assessing the cost of mitigating measures is outside the scope of this Study.

3.8.1 Expansion of network capacity

Any increase in traffic demand can be accommodated by an expansion of total network capacity to avoid degraded service quality. Total network capacity depends on available spectrum, spectrum efficiency of the technology deployed and number of sectors deployed with particular technology with a specified amount of spectrum. Therefore, the strategies available for increasing network capacity are:

- Spectrum refarming
- More efficient use of spectrum
- Expansion of network infrastructure

The practicability of each approach will vary depending on the actual network circumstances and there will be network cost trade-offs between different solutions (e.g. adding more spectrum and adding more infrastructure). In practice, it is not in the interests of the MNOs to allow service quality to be adversely affected and they need to maintain service quality at reasonable levels. If a MNO does not do this competition effects may result in churn of customers away from that MNO.

3.8.1.1 Spectrum refarming

Increasing the amount of spectrum deployed on sites/sectors will deliver extra network capacity. However, in the busiest areas of Hong Kong where traffic congestion is mostly likely to occur, most if not all spectrum has already been deployed on most sites.[32] The lack of availability of further spectrum for release before 2021 reduces the potential for increase of spectrum as a mitigating measure. It is noted that further spectrum could become available, including the 700 MHz band and possibly 5G bands in the longer term beyond 2021.

In the absence of new spectrum in the period considered by the Study, MNOs will have to make better use of existing spectrum holdings to meet traffic demand. As discussed above in Section 3.5.4, MNOs are likely to try to refarm more of their 2G and 3G spectrum over to 4G as the demand for these services declines with the shift to 4G services – though the timing and amounts which can be refarmed will depend on the traffic on their 2G and 3G networks.

In this Study, we have already used 2G, 3G and 4G traffic figures and refarming assumptions (as outlined in Section 3.5.4 above) to calculate DCO before applying mitigating measures. In general, it is assumed that the MNOs would intend to refarm frequencies in the 850 MHz, 900 MHz, 1800 MHz and 1.9 – 2.2 GHz bands for the provision of 4G service. In practice, MNOs will refarm their spectrums based on actual market needs.

3.8.1.2 More efficient use of spectrum

Technology evolution

The evolution of technology delivers increases in spectrum efficiency. For example, the move from 3G to 4G may typically deliver a long term 3-4x increase in the traffic carrying capacity. Increases in spectrum efficiency may also be achieved through improvements in technologies of transmission mechanisms over communications channels, performance of antenna, etc.[33]

One method of increasing overall spectrum efficiency is to refarm as much spectrum as possible to the most efficient technology (i.e. 4G). In practice, however, this can only be done if the population of deployed user devices is able to cope with the change and that it does not lead to a significant number of users who will lose service as a result of their devices no longer being able to use the replaced technology.

Upgrade of network

A second method is for MNOs to ensure that they implement upgrades to the network that deliver increased spectrum efficiency (e.g. LTE-A and MIMO) as soon as they become available. It is of equal importance that user devices are able to take advantage of the improved technology.

[32] Note that this is not the case for the MTR where large scale roll out of the spectrum in the 2.3 GHz and 2.5/2.6 GHz bands has yet to occur. The use of this spectrum is not expected to be widespread until into the early 2020s.

[33] These include improvement in areas of digital signal processing, modulation scheme, channel width, channel aggregation, antenna performance and radio frequency transmission, including the use of MIMO and beam forming.

3.8.1.3 Expansion of network infrastructure

Addition of more cells

Additional network capacity can also be provided through the addition of more cells to the network. However, in a very dense radio environment such as that found in Hong Kong there will be limitations as to how much infrastructure can be added to a network in a given area.

It is suggested that this may be achieved in Hong Kong by adding more sectors to an existing cell site, through the splitting of existing cell sites (e.g. 2 sites where there was one). The capacity of a network can also be increased by the deployment of additional small cells to serve focused high traffic areas. Advantages of small cells include boosting mobile network capacity by cell-splitting and frequency re-use thus bringing users closer to base stations and improving signal reception. Microcells can be deployed in urban areas to provide moderate coverage and capacity. Picocells and femtocells are deployed to serve small areas with high density traffic, thus providing low coverage and high capacity.

3.8.2 Offloading traffic onto another network (e.g. onto Wi-Fi infrastructure)

Assuming there is unlikely any new spectrum for mobile services by 2021, the assessment model considers the use of Wi-Fi as a potential mitigating measure, especially 5 GHz Wi-Fi with the potential to use large channel bandwidths. While deployment of Wi-Fi in high traffic areas (indoor and outdoor) could be a means of offloading traffic, it is revealed from discussion with the MNOs that many subscribers will opt to disable Wi-Fi on their phones outside of the home or workplace environment. As a result, the amount of additional traffic offload that can be assumed to move to Wi-Fi has been limited in the assessment model to a small percentage of overall traffic (less than 10%). However, it is likely that the culture of not using Wi-Fi outside of the home and workplace environment can be changed over time. In many countries such as the UK, the use of public Wi-Fi networks is widespread and a common strategy among MNOs is to deploy their own Wi-Fi networks in busy public areas to help manage mobile traffic and deal with network congestion.

In Hong Kong, the MNOs which do not have their own Wi-Fi networks can deploy Wi-Fi offloading in a number of ways. For example, they can provide their subscribers with an application which facilitates Wi-Fi calling over other Wi-Fi connections or partner with fixed network operators to provide public Wi-Fi in high traffic areas. It is also noted that OFCA has recently removed the restriction of handover between Wi-Fi access points. It will further help the increasing use of mobile data offload on Wi-Fi by the MNOs.

3.8.3 Migration of customers to technologies with higher spectrum efficiency

In recent years, smartphones and tablets capable of mobile broadband services have fast replaced the traditional voice-oriented mobile phones, and mobile data usage has been growing rapidly. The demand for mobile data unavoidably leads to a greater demand for spectrum for the provision of mobile services. To cope with such demand, MNOs may also implement strategies to accelerate migration of customers to technologies with higher spectrum efficiency (such as 4G) and to refarm the spectrum deployed for technologies with lower spectrum efficiency. This mitigating measure is applicable to technology specific (e.g. on 3G infrastructure) problems discussed in Section 4 below.

3.8.4 Use of other methods

In future, techniques such as Licensed Assisted Access (LAA), LTE Unlicensed (LTE-U) and other aggregation and heterogeneous network techniques could further improve network capacity. The practical and commercial realisation of these techniques is still some way in the future and they are not therefore considered in this Study. However, there is significant industry interest in these techniques at present and if deployed, they could further help alleviate network congestion and improve service quality.

4 Output of the assessment model

The results for all MNOs on a territory wide basis and for high traffic areas (i.e. the busiest 20% of sites) are set out in Sections 4.1 to 4.4 below. It should be noted that the results set out in this section do not include specific effects for the situation at MTR premises. For individual MNO, the results reported in Section 4.5 cover only the cases in which service quality issues are expected to be experienced, namely where the DCO value is greater than 0%. The rest of the output tables for individual MNO are provided in Appendix D for reference.

The outputs of the assessment model are shown in tabular form – by spectrum scenario and year. In the tables below a positive DCO value implies a possibility of service quality issues.

It should be noted that for all of the results presented they are only valid for the input parameters used and the spectrum scenarios identified. It is not possible to imply directly from the results presented what the DCO values might be for other scenarios which have not been modelled as part of this Study. It should also be noted that these busy hour traffic do not take into account instantaneous peaks in traffic – we only consider average busy hour traffic.

4.1 Analysis for all MNOs – all technologies

4.1.1 Territory wide

Table 4-1 shows the DCO results for all MNOs[34] on a territory wide basis for all technologies (2G, 3G, 4G) combined, which are zero across all years and all spectrum scenarios. The territory wide DCO results for all MNOs on the whole show that there is sufficient network capacity to accommodate all demand in all scenarios.

Table 4-1: All MNOs, all technologies (2G, 3G, 4G) territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

[34] All MNOs refer to the four incumbent MNOs in Hong Kong – CMHK, HKT, HTCL and SMT. For all the scenarios the DCO results are calculated based on the four incumbent MNOs only; the performance of the new entrant is not included in the DCO calculations for Scenarios 6A to 6E.

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.1.2 High traffic areas

Table 4-2 shows the DCO results for all MNOs in high traffic areas for all technologies (2G, 3G, 4G) combined, which are zero across all years and all spectrum scenarios. The DCO results for the high traffic areas show sufficient network capacity in all scenarios throughout the assessment period.

Table 4-2: All MNOs, all technologies (2G, 3G, 4G) high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.1.3 Conclusion for all MNOs – all technologies

The results for both territory wide and high traffic area analysis for all MNOs and all technologies indicate that the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands would not cause service quality issues when considered at this aggregate level in all scenarios considered in the Study.

4.2 Analysis for all MNOs – 2G services

The existing 2G services are supported solely by the frequency spectrum in the 900 MHz and 1800 MHz bands. The results for territory wide and high traffic areas analysis for the 2G services of all MNOs post the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands are shown in Table 4-3 and Table 4-4 below.

4.2.1 Territory wide

The 2G DCO results for all MNOs on a territory wide basis are shown in Table 4-3. It can be seen that in all scenarios, that the DCO remains at 0%, indicating that there would not be a service quality issue after the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands. It should be noted that in Scenario 1 it is assumed that the MNOs retain their existing spectrum assignments for 2G while in the rest of the scenarios, only the optimal amount required is retained for 2G by each MNO (i.e. [✂….] MHz for [✂….] and [✂….] MHz for [✂….]). Although MNOs retain less spectrum for 2G services in all scenarios other than Scenario 1, as 2G traffic is expected to decline to a low level during the modelling period, there is sufficient network capacity to meet the 2G traffic demand under all scenarios.

Table 4-3: All MNOs, 2G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.2.2 High traffic areas

The 2G DCO results for all MNOs in high traffic areas are shown in Table 4-4. It can be seen that with the specified amount of spectrum retained for 2G (i.e. the MNOs retain their existing spectrum assignments for 2G in Scenario 1, and [✂….] MHz for [✂….] and [✂….] MHz for [✂….] in all other Scenarios) the DCO remains at 0%, indicating that there will not be a service quality issue in all scenarios.

Table 4-4: All MNOs, 2G High traffic area – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.2.3 Conclusion for all MNOs – 2G services

The results for both territory wide and high traffic area analysis for 2G services indicate that the assumption for the amount of spectrum retained for 2G services is sufficient to maintain continuity of 2G services post the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands.

4.3 Analysis for all MNOs – 3G services

3G services are primarily supported by around 2×60 MHz of spectrum in the 1.9 – 2.2 GHz band. The DCO for 3G services is not directly affected by the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands as these two bands are mainly being utilised for GSM and LTE services by all incumbent MNOs. It is assumed in all scenarios that all spectrum in the 850 MHz and 900 MHz bands and a portion of the spectrum in the 1.9 – 2.2 GHz band for UMTS would be refarmed for LTE. The assumptions on the timing and the amount of spectrum being refarmed for LTE are the same for all scenarios (as shown in Appendix C) based on inputs from discussion with the MNOs. Therefore, the 3G DCO are identical across the scenarios being considered.

4.3.1 Territory wide

The 3G DCO results for all MNOs on a territory wide basis are shown in Table 4-5. The refarming of 850 MHz, 900 MHz and 1.9 – 2.2 GHz by the MNOs from 3G to 4G in 2021 effectively reduces the capacity of the 3G networks. However, it can be seen that territory wide DCO for 3G services remains at 0%, indicating that there will not be any service quality issues in all scenarios.

Table 4-5: All MNOs, 3G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.3.2 High traffic areas

The 3G DCO results for all MNOs in high traffic areas are shown in Table 4-6. Capacity of 3G networks is reduced in 2021 due to the refarming of 850 MHz, 900 MHz and 1.9 – 2.2 GHz for 4G, and there is a fall in 3G traffic as subscribers migrate to 4G. On an aggregated basis, the DCO remains at 0%, indicating that that there is sufficient capacity available in the 3G networks of the MNOs in all scenarios during the modelling period.

Table 4-6: All MNOs, 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.3.3 Conclusion for all MNOs – 3G services

The results for both territory wide and high traffic area analysis indicate that the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands would not have a significant impact on 3G service quality in all scenarios. The MNOs at an aggregate level should have sufficient spectrum in the 1.9 – 2.2 GHz band to sustain 3G traffic and avoid service quality issues. It is unlikely that the incumbent MNOs would invest in providing more 3G capacity and their strategy would be to take measures to speed up migration of subscribers to 4G services. Based on inputs from discussion with the MNOs, some MNOs may have to retain more spectrum in the 1.9 – 2.2 GHz band for 3G than others or have to migrate more 3G users to 4G. This is discussed further in Section 4.5.

4.4 Analysis for all MNOs – 4G services

In addition to spectrum in the 2.3 GHz and 2.5/2.6 GHz bands which is currently deployed for 4G services, a large proportion of the frequency spectrum in the 900 MHz and 1800 MHz bands has already been re-farmed for the provision of 4G services. It is therefore important to consider the effects of the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands for 4G services. The 4G DCO results are calculated by aggregating the entire supply of network capacity across the spectrum in the 850 MHz, 900 MHz, 1800 MHz, 2.3 GHz and 2.5/2.6 GHz bands based on inputs from discussion with the MNOs.

4.4.1 Territory wide

The 4G DCO results for all MNOs on a territory wide basis are shown in Table 4-7. Despite the increase in 4G traffic as a whole along the period, it can be seen that DCO values remain at 0%, indicating that there would not be service quality issues in the territory wide network in all scenarios. At the aggregate level for all MNOs, the effects of various spectrum re-assignment scenarios are small [✂….].

Table 4-7: All MNOs, 4G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.4.2 High traffic areas

The 4G DCO results for all MNOs in high traffic areas are shown in Table 4-8. The DCO values are all 0%, indicating that there would not be any service quality issues in high traffic areas in all scenarios.

Table 4-8: All MNOs, 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.4.3 Conclusion for all MNOs – 4G services

The output of the assessment model analysis suggests that the DCO results for all MNOs as a whole for territory wide network and high traffic areas are at a level where there is no service quality or continuity issue in all scenarios. In particular, the results show that the total demand on 4G services of the incumbent MNOs as a whole can be met under Scenarios 6A to 6E where a new entrant acquires spectrum in the 900 MHz and 1800 MHz bands with bandwidth ranging from 2×10 MHz to 2×20 MHz currently held by the incumbent MNOs.

4.5 Analysis for specific MNOs

This section provides more information on specific MNOs for each technology with a focus on cases which experience potential service quality issues. These issues only arise in high traffic areas and not for the territory wide network. For cases where there is no service quality issue, namely where DCO results are equal to 0%, the detailed output tables are reported in Appendix D. The amounts of spectrum in various bands deployed for each of the technologies (i.e. 2G, 3G or 4G) by individual MNOs are set out in Appendix C. This section also considers the ability of MNOs to mitigate the effects of losing part of their current spectrum holdings in the 900 MHz and 1800 MHz bands.

4.5.1 4G services – MNO1

The 4G DCO results for MNO1 shown in Table 4-9 indicate that MNO1 may experience service quality issues in 2023, notably in Scenario 6A [✂….].[35]

The demand on 4G services provided by MNO1 can be met in 2021 and 2022 after the spectrum re-assignment in all scenarios. The 4G DCO increases from 0% in 2022 to 14.6% in 2023 in Scenario 6A due to the increase in demand for 4G services, while the amount of spectrum utilised for the provision of 4G services in the [✂….] bands remains unchanged. The 4G DCO is 0% in the rest of scenarios in 2023.

Table 4-9: MNO1 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.6%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

[35] As assumed in the model, [✂….] MHz of spectrum in the 1800 MHz band is utilised for the provision of 2G services from 2021 to 2023 in Scenario 6A. Meanwhile, [✂….] MHz of spectrum in the [✂….] band and [✂….] MHz of spectrum in the [✂….] band are utilised by [✂….] for the provision of 4G service from 2021 to 2023 in Scenario 6A.

There are several possible mitigating measures that MNO1 can take, including increasing the number of 4G sectors or offloading more of its 4G traffic onto Wi-Fi. To accommodate capacity needs, MNO1 may consider adding more sectors to existing sites. Deployment of small cells and indoor femto cells can also be considered on a case by case basis depending on needs.

Table 4-10 shows the 4G DCO values for which MNO1 increases the number of 4G sectors by 10% from 2016 onwards. This reduces the 4G DCO value for Scenario 6A from 14.6% to 6.1%, which remains to be greater than zero.

Table 4-10: MNO1 – 4G high traffic areas – DCO (increase number of 4G sectors by 10% from 2021 onwards)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.1%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

With more Wi-Fi offload[36], the situation in 2023 is further improved as shown in Table 4-11 and the 4G DCO for Scenario 6A is now reduced from 6.1% to 0%, indicating that the service continuity issue can be effectively mitigated with the application of these mitigating measures.

Table 4-11: MNO1 – 4G high traffic areas – DCO (increase number of 4G sectors by 10%, more Wi-Fi offload)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

[36] As discussed in Section 3.8, the scope for additional Wi-Fi offload may be limited and thus the assumption is that this is limited to less than or equal to 10% of the MNO's overall 4G traffic.

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.5.2 3G services – MNO2

The 3G DCO results for MNO2 shown in Table 4-12 indicate that it would face 3G service quality issues in high traffic areas even with the retention of [✂….] MHz for 3G and refarming of only [✂….] MHz in the 1.9 – 2.2 GHz band for 4G from 2021 onwards as assumed in the model. The demand will exceed 80% of the total network capacity and the 3G DCO results are 4% in 2021. Where the DCO is greater than zero, the relevant cell(s) are highlighted. As explained in Section 4.3 above, the assumptions on the timing and the amount of spectrum being refarmed for LTE are the same for all scenarios (as shown in Appendix C) based on inputs from discussion with the MNOs. Therefore, the 3G DCO are identical across the scenarios being considered.

The 3G DCO results in all scenarios reduce from 4% in 2021 to 0% in 2022 due to the decrease in 3G traffic from 2021 to 2022.

Table 4-12: MNO2 – 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%

One possible mitigating measure is that MNO2 should delay the refarming of spectrum in the 1.9 – 2.2 GHz band by at least another year, in effect retaining [✂….] MHz of 3G spectrum until 2022 or later. This reduces the 3G DCO from 4% to 0% in all scenarios as shown in Table 4-13. While this mitigation will eliminate the 3G issue, it may exacerbate the 4G service quality issues faced by MNO2 as discussed below. In addition, it is likely to be an inefficient use of spectrum for MNO2 to retain [✂….] MHz of spectrum for 3G into the 2020s. It is more likely in practice that MNO2 will seek to migrate traffic from its 3G network to its 4G network and this would be effective in reducing the resulting 3G DCO to 0% in 2021 in all scenarios.

Table 4-13: MNO2 – 3G high traffic areas – DCO (delayed refarming of 1.9 – 2.2 GHz to 2022)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.5.3 4G services – MNO2

The 4G DCO results for MNO2 shown in Table 4-14 indicate that it will face potential service quality issues in 2023 in Scenario 6B where the new entrant acquires 2×15 MHz of spectrum currently held by [✂….]. In this scenario, the 4G DCO result is 4.3%. Note that this has not taken into account the impact of mitigating 3G issues discussed above.

Table 4-14: MNO2 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Taking into account the impact of retaining more spectrum by MNO2 for 3G services for an extra year until 2022 as mentioned in section 4.5.2 above, the performance of its 4G network shows further potential service quality issues.

To mitigate the potential service quality issues stemming from the loss of spectrum to new entrants and delayed refarming of the spectrum in the 1.9 – 2.2 GHz band to 4G, MNO2 can consider increasing the number of sectors deployed in 4G high traffic areas. Table 4-15 shows the DCO results post mitigation of increasing the number of 4G sectors by 10% from 2016 onwards. With this measure, the DCO for Scenario 6B is reduced to 0%.

Table 4-15: MNO2 – 4G high traffic areas – DCO (increase number of 4G sectors by 10% from 2016)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.5.4 Conclusion for specific MNOs

The output of the assessment model indicates that there are specific service quality issues separately faced by two individual MNOs during the 2016-2023 period in certain scenarios. However, these can be addressed with different mitigating measures.

- MNO1 may potentially face a minor 4G service quality issue in 2023 in Scenario 6A [✂….]. The probability of this happening is considered to be extremely low but in the event that this scenario materialises, MNO1 should be able to mitigate the impacts on its 4G service quality by increasing the number of 4G sectors and offloading more 4G traffic to Wi-Fi.

- MNO2 may potentially face a minor 3G service quality issue in 2021 in all scenarios considered by the model. One possible mitigating measure is to delay the refarming of the spectrum in the 1.9 – 2.2 GHz band by at least another year, in effect retaining [✂….] MHz of 3G spectrum in the 1.9 – 2.2 GHz band until 2022 or later. In practice this may not be an efficient use of spectrum and it is more likely that MNO2 should be able to mitigate the impacts by migrating traffic from its 3G network to its 4G network.

- MNO2 may potentially face a minor 4G service quality issue in 2023 in Scenario 6B where a new entrant acquires 2×15 MHz of frequency spectrum in the 900 MHz and 1800 MHz bands currently held by [✂….]. This may be aggravated by its delay in refarming 1.9 – 2.2 GHz as mentioned above which would exacerbate the service quality issue in the period 2021 – 2023. MNO2 should be able to mitigate the impacts by increasing the number of 4G sectors.

4.6 Impacts on service quality with a new entrant

It can be seen from the DCO results that it is possible to accommodate, with appropriate mitigation, a new entrant for Scenarios 6A to 6E where the new entrant is assumed to acquire spectrum in the 900 MHz and 1800 MHz bands with bandwidth ranging from 2×10 MHz to 2×20 MHz currently held by incumbent MNOs. We consider Scenarios 6A to 6E as the likely worst case scenarios in the model. In the cases where the new entrant's assumed spectrum leads to potential service quality issues for incumbent MNOs, notably MNO1 and MNO2, there are possible mitigating measures available to the incumbent MNOs to address these problems as discussed in Section 3.8.

4.7 Sensitivity analysis

This section provides the results of the sensitivity analysis for the following cases:

- High traffic forecast[37] is used instead of the forecast based on MNOs' data

- An increase in the total number of sites for all MNOs by 10% from 2016-2023

- A decrease in the total number of sites for all MNOs by 10% from 2016-2023

[37] The high traffic forecast is derived by applying Cisco's forecast growth rates to current mobile traffic in Hong Kong. Appendix A provides more details.

- No improvement in 4G spectrum efficiency from 2016-2023

In Section 4.1 to Section 4.4, the DCO results for 2G, 3G and 4G services on a territory wide basis show that there is sufficient network capacity to accommodate all traffic demand in all scenarios throughout the modelling period. Therefore, the analysis is carried out for high traffic areas (for all MNOs) and not for the territory wide network as it is only in the former case where service quality issues will arise.

For the change in site numbers, only 3G and 4G are assessed as these are likely to be the key priority for MNOs in planning their networks.

4.7.1 High traffic forecast

Table 4-16 shows the 2G DCO results in high traffic areas for all MNOs. Although it is assumed that there is a higher 2G traffic forecast compared to the MNOs' forecast in Section 4.2.2, the DCO values are still 0% and thus service quality issues for 2G will not arise.

Table 4-16: All MNOs, 2G high traffic areas (high traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4-17 shows the 3G DCO results in high traffic areas for all MNOs. Similarly, with a higher 3G traffic forecast, the DCO values are still 0%. The 2G and 3G DCO results in high traffic areas indicate that there is sufficient network capacity to accommodate a higher traffic demand in all scenarios during the modelling period.

Table 4-17: All MNOs, 3G high traffic areas (high traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4-18 shows the 4G DCO results in high traffic areas for all MNOs. There is a higher traffic forecast and the DCO value exceeded zero marginally in 2023 under Scenario 6A as highlighted. With the advancement of mobile technology, it is expected that MNOs concerned will strive to maintain the service quality by implementing appropriate mitigating measures.

Table 4-18: All MNOs, 4G high traffic areas (high traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.7.2 Increase in the number of sites by 10%

Table 4-19 shows the 3G DCO results in high traffic areas for all MNOs assuming a 10% increase in the number of sites. As expected, with the higher overall network capacity calculated for all MNOs, the DCO values are all zero.

Table 4-19: All MNOs, 3G high traffic areas (10% increase in the number of sites, MNOs' traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4-20 shows the 4G DCO results in high traffic areas for all MNOs. With the higher overall network capacity calculated for all MNOs, the DCO values are all zero.

Table 4-20: All MNOs, 4G high traffic areas (10% increase in the number of sites, MNOs' traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.7.3 Reduction in the number of sites by 10%

Table 4-21 shows the 3G DCO results in high traffic areas for all MNOs assuming a 10% reduction in the number of sites. With the lower overall network capacity calculated for all MNOs, DCO values are still all zero.

Table 4-21: All MNOs, 3G high traffic areas (10% reduction in the number of sites, MNOs' traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4-22 shows the 4G DCO results in high traffic areas for all MNOs assuming a 10% reduction in sites. With the lower overall network capacity calculated for all MNOs, the DCO values are still all zero. The 3G and 4G DCO results in high traffic areas indicate that although the number of sites are reduced by 10%, there is still sufficient network capacity to accommodate the demand in all scenarios during the modelling period.

Table 4-22: All MNOs, 4G high traffic areas (10% reduction in the number of sites, MNOs' traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.7.4 No improvement in 4G spectrum efficiency

Table 4-23 shows the 4G DCO results in high traffic areas for all MNOs assuming spectrum efficiency for 4G (1.3 bits/sec/Hz) does not improve over the 2016 – 2023 period. With the lower overall network capacity calculated for all MNOs over the modelling period, the DCO values are still all zero.

Table 4-23: All MNOs, 4G high traffic areas (4G spectrum efficiency constant, MNOs' traffic forecast) – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

5 Impacts on the continuity of mobile services at MTR premises

5.1 Introduction

The MTR is a special mobile environment in terms of the design of network infrastructure for the provision of mobile coverage. It is predominantly a high traffic indoor area with confined spaces (on station concourses, platforms and in rail tunnels). The constraints of such an environment mean that it is difficult to apply the assessment model, which is designed to reflect the operation of a large network as a whole with the capacity of all the base stations considered on an aggregate basis.

Mobile services at MTR premises are currently provided by IRS, common radio signal distribution systems currently operating in the 900 MHz (including the 850 MHz and EGSM band), 1800 MHz (1720 – 1780 / 1815 – 1875 MHz in 6 pre assigned 2×10 MHz slots) and 1.9 – 2.2 GHz bands, combining the signals from all the four incumbent MNOs for transmission at MTR stations, platforms and adjoining tunnels. At present, there are two systems of IRS in operation at MTR premises. One IRS supports the 900 MHz band and another IRS supports the 1800 MHz and 1.9 – 2.2 GHz bands.

It is not easy to model the MTR environment and the sort of full engineering modelling exercise required is outside the scope of this Study. This is due to the more granular and specific characteristics of each MTR location. Under these circumstances the simplifying assumptions and averaging effects that can be taken advantage of in the assessment model become less reliable to the extent that the result can be misleading. Also, establishing a demand profile for stations and on the trains requires a specific forecasting methodology. Forecasts from Cisco and other industry players, which are good for network wide modelling are unreliable when looking at an environment like the MTR. For this reason, we are not presenting modelling results for the MTR and our view given below is based on a qualitative assessment.

5.2 Architecture of IRS at MTR premises

In general, the two systems of IRS are of similar design and both of them consist of:

- POIs, located in interconnection rooms, where interconnection occurs between the MNOs' systems (base stations) and the IRS. Interconnection rooms / POIs are typically located at station premises.

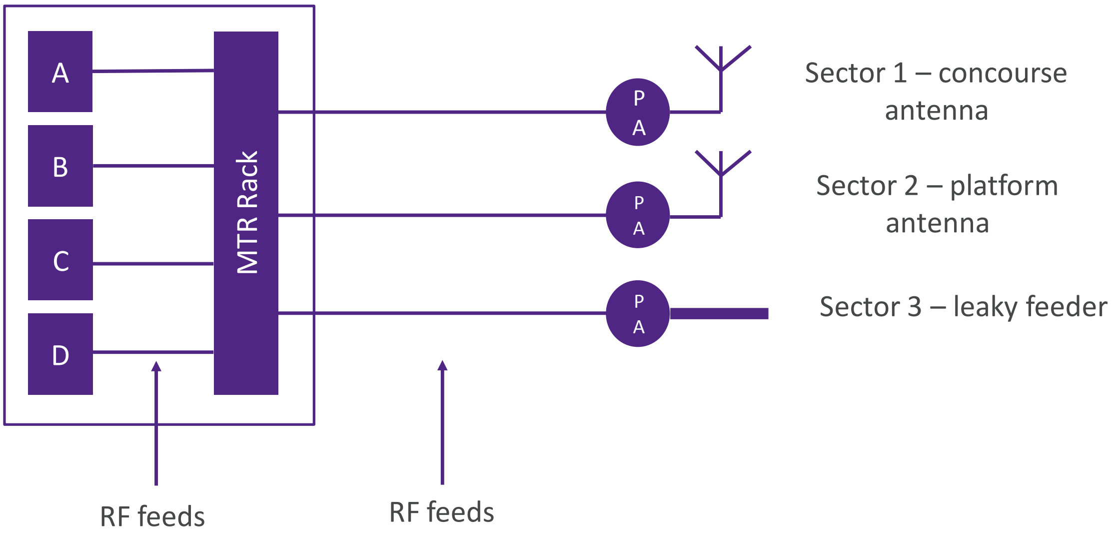
- A distribution network for transmitting the mobile radio frequency (RF) signals in the stations and tunnels.

The MTRC is responsible for all aspects of transmission of the RF signal within the IRS. It should be noted that the IRS is only a transmission entity and it does not switch or route traffic.

The system is configured as described below (see Figure 5-1):

- The RF signals from MNOs' networks are connected to the POIs
- The RF signals are then combined by a combiner for each frequency band.
- The combined RF signals are fed either to a station platform / concourse area or into the tunnels.
  - In the station concourse and platform areas, the RF signals are amplified and fed to sector antennas
  - In the tunnels, the RF signals are fed to power amplifiers that feed the leaky feeder cables
  - The return path (uplink) is transmitted back to the IRS POI, and is then sent back to each MNO.

Figure 5-1: IRS system architecture



Each POI is equivalent to 1 sector. There can be different numbers of sectors across frequency bands. [✂….].

[✂….].

5.2.1 Spectrum supported

The IRS supporting the 900 MHz band operates at the following spectrum bands:

- 850 MHz and 900 MHz bands (full band throughout most of the MTR premises).

It is noted that the IRS supporting the 900 MHz band, except for East Rail Line and West Rail Line, is planned to be upgraded with frequency agile equipment which will be ready for service by 2021. The upgraded IRS will then be configurable to accommodate changes of the operating frequency bands of the MNOs depending on the outcome of the re-assignment of the spectrum in the 900 MHz band.

The IRS supporting the 1800 MHz and 1.9 – 2.2 GHz bands operates at the following spectrum bands:

- 1800 MHz band (2×60 MHz out of the 2×75 MHz assigned except for certain new lines including West Island Line, South Island Line, Kwun Tong Line Extension, where 2×75 MHz will be available)
- 1.9 – 2.2 GHz band (full band throughout all the MTR premises)
- 2.3 GHz and 2.5/2.6 GHz bands, but only implemented for a small number of new stations recently brought into service.

In this regard, it should be noted that the provision of 4G services at MTR premises by all MNOs relies primarily on the 2×60 MHz of spectrum in the 1800 MHz band at present.

5.2.2 Transmission in the tunnels

Mobile signals are provided in the tunnels using leaky feeder systems. These feeder systems transmit the downlink RF signals to terminals and receive the uplink RF signals from mobile devices. At present single leaky feeders are used but it is understood from the MTRC that in future it may be possible to deploy dual feeders with sufficient diversity to provide a MIMO capability in the tunnels. It is unclear when this enhancement will take place and how long it will take to deploy. It should be noted that the performance improvement that might occur with such an arrangement won't necessarily match that expected in outdoor environments.[38]

5.2.3 Transmission at stations

Mobile signals are provided via antennas fed from the POIs. Each area of the station / concourse would normally be a separate sector. For stations where the concourse and platform areas are above ground there may be coverage from outdoor sites in addition to any coverage provided by the IRS.

[38] It's not clear how effectively the MIMO channel characterisation would function with a train moving relatively fast in close proximity to the leaky feeder antennas.

5.2.4 IRS upgrade plan

It is noted that MNOs have been working closely with the MTRC on upgrading the IRS at MTR premises. The IRS supporting the 900 MHz band, except for the East Rail Line and West Rail Line, are planned to be upgraded with frequency agile equipment by 2021. That means the IRS can be reconfigured to accommodate any change of the operating frequency bands of the MNOs.

The IRS supporting the 1800 MHz and 1.9 – 2.2 GHz bands is the subject of two phases of coverage enhancement programme for the busiest 18 MTR stations with high passenger flow (called Phase 1 and Phase 2). [✂….] At these 18 locations, the system will be upgraded to support 1800 MHz (1710 – 1785 / 1805 – 1880 MHz), 1.9 – 2.2 GHz, 2.3 GHz and 2.5/2.6 GHz bands, together with the installation of the frequency agile equipment. It is expected that these two phases of coverage enhancement programme will be completed by 2019. The upgrades will provide a significant increase in capacity at these locations (with 2.3 GHz and 2.5/2.6 GHz bands, and increased bandwidth in the 1800 MHz band). With this additional capacity, the potential impacts on service quality when the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands occurs should be reduced. However, there is yet to be any agreement between MTRC and MNOs about upgrade of the IRS for the Remaining Stations, which consist of 43 MTR stations and adjoining tunnels.

There are practical issues with upgrading mobile infrastructure at MTR premises. The technical and logistic aspects of this are described further in Section 5.3 below. Plum noted from its meetings with MNOs and the MTRC that it can, in reality, take a long time for agreement to be reached on upgrade programmes and for them to be executed. For the Remaining Stations, there is not yet an agreement reached between MTRC and MNOs as of August 2016. Should there be any agreement to upgrade these stations, it would take around three years to plan and replace the IRS to add capacity in the 2.3 GHz and 2.5/2.6 GHz bands (due to the coordination work and IRS upgrade time required). Hence, there is a low probability that an additional enhancement programme after Phase 1 and 2 could be completed by 2021.

5.3 Implementing changes to IRS deployed at MTR premises

Changes are generally implemented in non-operating hours of the MTR between 01:30 and 04:30 in the morning. This limited time window restricts the amount of engineering and testing work that can be done each day during the transitional period when the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands occurs.

The MTRC advised that any change implemented on the IRS requires physical disconnection of the MNOs' equipment from the POI to measure the frequency and power level of the signals. This requirement applies irrespective of whether frequency agile equipment is in use or not. Where frequency agile equipment is not installed it may also be necessary to make a physical change to the combiners / filters at POIs when there is a change in the frequency assignments. This can take a considerable time.

For the IRS supporting the 900 MHz band, except for East Rail Line and West Rail Line, frequency agile equipment will be provided by 2021 and the IRS will then be configurable. However, given the stringent procedures governing the conduct of engineering work at MTR premises, any reconfiguration of the operating frequency bands still requires time for testing and system commissioning subject to the technical coordination among the concerned parties. It is noted that a transitional period of at least three months is still needed.

For the IRS supporting the 1800 MHz and 1.9 – 2.2 GHz bands, there is yet to be any agreement between the MTRC and MNOs about upgrade of the IRS for the Remaining Stations to include the 2.3 GHz and 2.5/2.6 GHz bands for supporting 4G services with frequency agile equipment. Any spectrum reshuffling in the 1800 MHz band will therefore take time for system reconfiguration or upgrade of the IRS in the Remaining Stations. It is noted that the length of the transitional period will depend on the scope of system reconfiguration or upgrade work required, which ranges from three months for system re-configuration to three years if full system upgrade is needed.

The MTRC noted that it could be difficult to accommodate a new entrant using the existing IRS but that with good planning this could be done over a period of time (probably several years). There would be both technical and commercial issues to be resolved with the current MNOs and the new entrant.

5.4 Use of Wi-Fi offloading

The MTRC confirmed that 2.4 GHz Wi-Fi is being “cautiously” deployed in station areas. There are significant concerns about the deployment of 5 GHz Wi-Fi due to potential interference to train operation systems. The MTRC advised of the need to carry out a study to look at the 5 GHz issues at some locations on the MTR. There is no indication of when such a study may take place. These restrictions limit the potential for use of Wi-Fi as a mitigating measure at MTR premises.

5.5 Potential impacts on service continuity

Subject to the outcome of the re-assignment, if there is any change in the frequency assignments such that the MNOs are unable to retain the part of their respective spectrum holdings in the 1800 MHz band for the provision of 4G services, there may be impacts on service continuity at MTR premises to varying degrees. There are two cases to consider:

- For stations with IRS that have been upgraded with frequency agile equipment and in addition support 2.3 GHz and 2.5/2.6 GHz bands, the potential impacts on service continuity at these stations when the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands occurs should be minimized. That notwithstanding, mobile services may still be affected during the transitional period as described in section 5.3 above in the case of any spectrum re-shuffling among the MNOs or under the situation that any MNO cannot retain its existing spectrum holding in the 1800 MHz band.

- For the Remaining Stations with IRS that have not been upgraded (i.e. do not support 2.3 GHz and 2.5/2.6 GHz bands), the provision of 4G services primarily relies on the 2×60 MHz of the 1800 MHz band and hence 4G services would likely be affected should there be any variation in the frequency assignments in the band. The potential impacts on service continuity for 4G services in the Remaining Stations will be very high, and service users will likely be adversely affected as a long lead time will be required for the IRS in these stations to be reconfigured or upgraded to support the 2.3 GHz and 2.5/2.6 GHz bands. The length of such a transitional period will depend on the scope of system reconfiguration or upgrade work required (ranging from three months for system re-configuration or up to three years if full system upgrade is needed). A lengthy transitional period means that service users will be adversely affected on a prolonged basis. It will also affect users of the 3G network, as the 4G mobile data users will migrate onto the 3G network when the 4G services faced serious service continuity issues.

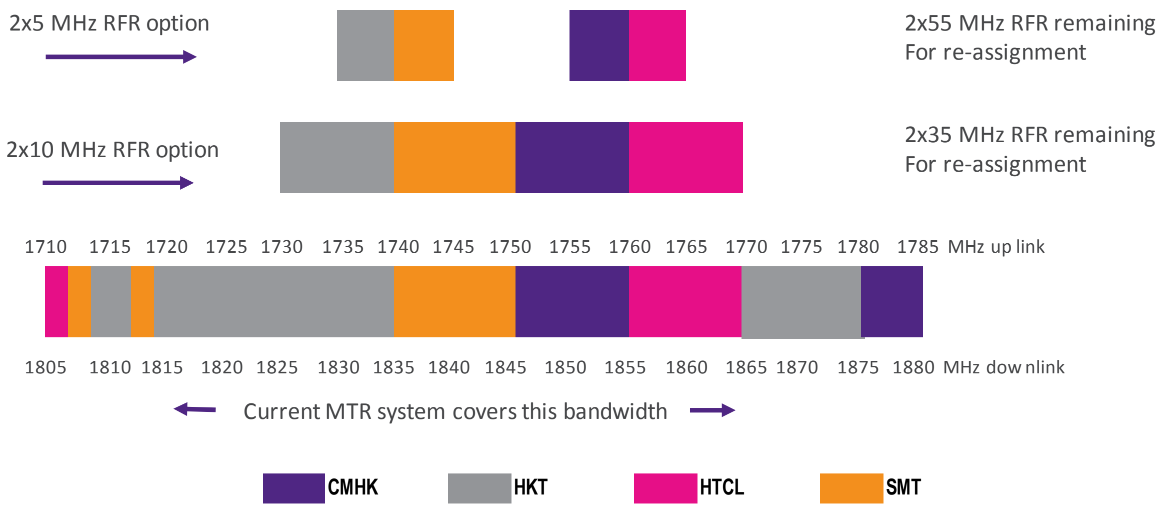
5.6 Recommendation on RFR spectrum

Having considered the fact that all MNOs rely primarily on the 1800 MHz band to provide 4G services at MTR premises and in addition, the 1800 MHz band is also the core LTE band in most locations in the territory, a possible solution to the problem in the MTR premises could be that each MNO will be offered 2×10 MHz of spectrum in the 1800 MHz band on a RFR basis so that the incumbent MNOs will be able to retain their existing spectrum assignments within the frequency range 1720 – 1780 / 1815 – 1875 MHz. It is noted that the offer of 2×10 MHz RFR spectrum in the 1800 MHz band is more suitable than the 900 MHz band, because only three MNOs have holdings in the 900 MHz band and there is insufficient spectrum to accommodate more than 2×5 MHz RFR spectrum for each MNO. The 1800 MHz band is currently deployed by all four MNOs for the provision of 4G services at MTR premises and all IRS installed there support this frequency band. It follows that the offer of RFR spectrum in the 1800 MHz band would be a more practical and reasonable solution to address the potential impacts on 4G service continuity at MTR premises. The suggested solution could also reduce the risk of additional fragmentation of spectrum arising from the auction process. This approach will still provide a total of 2×60 MHz (2×35 MHz in the 1800 MHz band and 2×25 MHz in the 900 MHz band) to be re-assigned by auction.

An alternative will be to permit only 2×5 MHz to be re-assigned to each MNO on an RFR basis in the 1800 MHz band. This approach would provide a total of 2×80 MHz (2×55 MHz in the 1800 MHz band and 2×25 MHz in the 900 MHz band) to be re-assigned by auction. However, it will run the risk that subject to the auction result, MNOs may not be able to retain 2×10 MHz of the spectrum in the 1800 MHz band currently deployed for provision of 4G services at MTR premises. In addition, the use of 2×5 MHz for each MNO would still involve system adjustments to the IRS that may complicate the POI design.

The above two options are illustrated in Figure 5-2 below.

Figure 5-2: RFR options



6 Conclusions

In this final section we summarise our conclusions from the results of the assessment model. The purpose of the assessment model is to test various scenarios to see whether they create situations that would lead to service quality issues post the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands. Where such problems are identified, mitigating techniques can be applied to reduce the service quality impacts. The assessment model considers the case of the territory wide network and the busiest 20% of sites (high traffic areas), with analyses by MNO and by technology.

We have also considered a number of related issues including the impact of a new entrant and made recommendation on the RFR spectrum.

6.1 Outcome of the assessment model

The assessment model has been used to test a set of spectrum scenarios as shown in Section 3.7. The scenarios have been tested against a traffic demand forecast based on inputs from the MNOs and suitably adjusted by Plum as described in Section 3.3. The results of the assessment model for 2G, 3G and 4G services for all MNOs for the territory wide network shows DCO values below the threshold set for presence of service quality issues.

6.1.1 Impacts on 2G services

The assessment model uses spectrum assumptions for 2G based on the MNOs' inputs, namely that [✂….] would retain [✂….] MHz and the other MNOs [✂….] MHz. The results indicate that this amount of spectrum should be sufficient for these services. However, this may be an inefficient use of spectrum as all 2G traffic could be handled in less than [✂….] MHz and there may be the opportunity for a MVNO or network sharing arrangement to handle residual 2G traffic in the longer term.

6.1.2 Impacts on 3G services

The results for both territory wide and high traffic area analysis indicate that the re-assignment of the frequency spectrum in the 900 MHz and 1800 MHz bands will not have a significant impact on 3G service quality. The MNOs should have sufficient spectrum in the 1.9 – 2.2 GHz band to sustain 3G traffic and avoid service quality issues although this may mean that some MNOs have to retain more spectrum in the 1.9 – 2.2 GHz band for 3G than others or have to migrate more 3G users to 4G networks.

6.1.3 Impacts on 4G services

The output of the assessment model analysis shows that for all MNOs, for both territory wide network and in high traffic areas, the 4G DCO results are at a level where there is no impact on service quality. However, there are some instances in which two individual MNOs would potentially experience minor service quality issues for 3G and/or 4G services.

6.1.4 Impacts on individual MNOs

While the above network wide assessments suggest that there would be an acceptable service quality for most of the scenarios under consideration in the Study in general, there are some instances where specific MNOs would encounter positive values of DCO indicating possible service quality issues:

- There could be minor 4G service quality issues for MNO1 in 2023 under Scenario 6A [✂….]. This can be mitigated by building more 4G sectors and increasing Wi-Fi offload.
- There could be minor 3G service quality issues for MNO2 in 2021 under all scenarios considered in the Study. This can be mitigated by delaying refarming of 1.9 – 2.2 GHz to 4G by MNO2 by a year to 2022 (there is a consequential impact on MNO2's 4G DCO), or migrating traffic from MNO2's 3G network to its 4G network.
- There could be minor 4G service quality issues for MNO2 in 2023 under Scenario 6B where a new entrant acquires 2×15 MHz of spectrum currently held by [✂….]. This can be mitigated by building more 4G sectors by MNO2 – note that the mitigation also includes dealing with the additional impact to MNO2's 4G services in 2021-2023, due to delaying the refarming of spectrum in the 1.9 – 2.2 GHz band by a year to 2022.

In all of the above cases it appears that viable mitigating measures exist. It should be noted that MNOs will generally monitor and mitigate specific problems as they arise.

6.1.5 Impacts on service quality with a new entrant

It can be seen from the results that it is possible to accommodate a new entrant under Scenarios 6A to 6E. In the cases where the new entrant's acquired spectrum leads to potential service quality issues for two individual incumbent MNOs, there are possible mitigating measures available to the incumbent MNOs to address these problems.

6.2 Sensitivity analysis

A number of sensitivity checks are carried out on traffic forecasts, infrastructure (number of sectors) and spectrum efficiency. The following sensitivity checks are considered in the report:

- Higher traffic forecast (all MNOs) – this has not pushed DCOs above zero except for one scenario (6A) in which the DCO is marginally above the threshold in 2023. However this is only marginal and could well be within the margin of error.

- Increase the total number of sites by 10% (all MNOs) – this increases 3G and 4G capacity and hence it improves the service quality expectation.

- Decrease the total number of sites by 10% (all MNOs) – this reduces capacity for 3G and 4G with the potential to have impacts on service quality but the DCO results remain at zero.

- 4G spectrum efficiency does not increase (all MNOs) – this reduces capacity for 4G with the potential to have impacts on service quality but the DCO results remain to be zero.

The sensitivity checks, especially those that are expected to have impacts on service quality, show that with one small exception, that there is a reasonable margin of safety with the assessment model results.

6.3 Impacts on the continuity of mobile services at MTR premises

A qualitative assessment has been carried out for the provision of mobile services at MTR premises given the difficulties in the application of the assessment model in the MTR environment. At stations that have been upgraded with frequency agile equipment and in addition support the 2.3 GHz and 2.5/2.6 GHz bands, the potential impacts on service continuity when the re-assignment of spectrum in the 900 MHz and 1800 MHz bands occurs should be reduced. At stations that have not been upgraded (i.e. do not support 2.3 GHz and 2.5/2.6 GHz bands) and are reliant on legacy equipment, the potential impacts on service continuity for 4G services would need attention, if the incumbent MNOs cannot get back some or all of their existing spectrum holdings from auction.

A possible solution to this problem can be that any spectrum offered on a RFR basis should be within the 1800 MHz band and constrained to within the frequency range 1720 – 1780 / 1815 – 1875 MHz. An RFR of 2×10 MHz for each MNO would resolve the service continuity issues likely to be encountered for 4G services after the re-assignment of the spectrum in the 900 MHz and 1800 MHz bands.

Appendix A: Data provided by MNOs

The MNOs were requested to provide data to support the analysis of future spectrum requirements in the 900 MHz and 1800 MHz bands. Table A-1 shows the list of information requested.

Table A-1: Information requested from MNOs

Category	Data requested
Network traffic	• Subscriber and traffic projections to 2024 for voice, messaging, data and M2M (if any) services across 2G, 3G and 4G networks at indoor and outdoor locations. • Projections to 2024 for inbound roaming traffic (voice and data across 2G, 3G and 4G networks), using the supplied template. • Traffic profile for voice and data by time of day / day of week – in particular the busy hour and percentage of total daily traffic is carried during this hour. Is this expected to change in the future and if so how? • Current average split between uplink and downlink traffic across the network and how this varies by site type, geographic location and time of day. Is the split expected to change in the future? • Split between traffic served by indoor and outdoor base stations on the network. Is information available on the geographic distribution of voice and data traffic across the network, or can specific high traffic areas be identified? In particular, is information on traffic loading at individual base station locations available? If so, please specify the average busy hour cell loading across the network and the loading for the busiest 20% of sites, for 2G, 3G and 4G networks. • The average busy hour loading at 2G, 3G and 4G base stations serving the MTR stations and along the route of the MTR. • Proportion of subscribers use phones that can only operate on 2G networks.
Network infrastructure	• Details of existing and planned base station sites, including macro sites, major indoor installations and public Wi-Fi hotspots. • Details of coverage currently provided on the indoor and underground sections of the MTR network, including frequency bands and technologies deployed. • Current configuration of integrated radio systems deployed on the MTR and at other high traffic locations, in particular whether the hardware deployed (amplifiers, filters, antennas, etc.) is frequency specific. Please describe any planned

Category	Data requested
	changes to the configuration of these systems over the next 3-5 years. • Specific obstacles encountered in gaining access to base station sites (macro, micro, indoor, MTR). • Extent of infrastructure sharing between networks, e.g. proportion of different site types that are shared and between which MNOs, extent of sharing (sites, towers, antennas, full RAN) and whether trend is towards further sharing in future. • How networks are planned with regard to whether to deploy macro versus micro cells, or indoor versus outdoor base stations. • Quality of Service criteria used when planning 2G, 3G and 4G networks – e.g. percentage of voice calls blocked, minimum cell edge data rate and assumed cell loading during the busy hour. • Percentage of base station sites of each type that uses each available frequency band and any anticipated changes over the next 2 years. • Deployment of integrated radio systems across the network in the 900 MHz band and 1800 MHz band and whether these require any hardware modification in the event of a change to the frequency holdings in these bands.
Utilisation of spectrum holdings	• Current utilisation of spectrum holdings (MHz of paired spectrum in each band) for 2G, 3G and 4G technologies and any planned changes in the next 2 years. • Typical spectrum efficiency (in bits/secs/Hz) for each network technology achieved in practice and if they vary significantly, e.g. depending on type of site or geographic location. If so, by how much? • Future plan of re-farming radio spectrum including the 900 MHz and 1800 MHz bands or any other band.
New service and technology developments	• Details of any existing or planned long term contracts relating to machine to machine communications that would require long term access to 2G or 3G technology. • Current or planned deployment of MBMS or other mobile broadcast technologies within you network. • Current or future planned deployments of new technologies such as VoLTE, carrier aggregation or LTE operation in licence exempt spectrum. • Any other techniques currently or expected to be deployed in the future in order to enhance network performance or capacity, or to facilitate migration to new technologies. Examples include MIMO antenna systems, dynamic spectrum sharing between GSM and LTE networks and load balancing between adjacent

Category	Data requested
	cells. • Steps involved in upgrading a base station to accommodate a new generation technology or to modify the frequencies deployed – in particular is there likely to be any significant downtime during the upgrade? Are different types of base station (macro, micro, indoor small cells) affected in different ways and if so, how? • Mitigation measures including any investment in network infrastructure plan during the three-year notice period prior to the re-assignment of the frequency spectrum in 2020/21.

A.1 Issues with data provided

While the four MNOs were generally cooperative in the information gathering process, not all provided the full set of historic and forecast data requested. Table A-2 provides a summary of the information provided by each MNO.

Table A-2: Summary of data provided by each MNO

MNO	Data provided
[✂….]	Historic voice and data traffic from 2012 to March 2016 for 2G, 3G and 4G provided. Historic subscriber numbers from 2013 to 2015 for 2G, 3G and 4G provided. For the period from end 2016 – 2021, only aggregated forecast data traffic and aggregated subscriber number (without breakdown by technology) were provided. A constant growth rate of [✂….] per annum was assumed.[39] Base station numbers, sectors, frequency deployments and utilisation provided for 2016 but not for 2020.
[✂….]	Historic and forecast voice and data traffic from 2012 to 2024 for 2G, 3G and 4G provided. Subscriber numbers from 2012 to 2024 for 2G, 3G and 4G services provided. Base station numbers, sectors, frequency deployments and utilisation for 2016 and 2020 provided.
[✂….]	Voice and data traffic and subscriber numbers in 2015 and up to March 2016 for 2G, 3G and 4G provided. No forecast data traffic or subscriber number was provided. Base station numbers, sectors, frequency deployments and utilisation provided for 2016 but not for 2020.

[39] This value is similar to the 2015 – 2020 CAGR for the Asia Pacific region in Ericsson's 2015 Mobility Report. We note that using a regional forecast which tends to be skewed towards developing APAC countries may not accurately reflect the more mature and developed state of the Hong Kong market.

MNO	Data provided
[✂….]	Historic and forecast voice and data traffic from 2012 to 2024 for 2G and 4G provided. Historic voice data traffic of 3G from 2013 to March 2016 (without forecast) provided by [✂….]. Subscriber numbers from 2012 to 2024 for 2G, 3G and 4G services provided. Base station numbers, sectors, frequency deployments and utilisation for 2016 and 2020 provided.
[✂….]	Number of [✂….] and [✂….] sites in [✂….] network and breakdown by type of site; only 2016 information provided.

One of the key inputs for the assessment model is the mobile traffic demand for each MNO. [✂….] both provided comprehensive forecasts up to 2024; however, as shown in Table A-2 above, there were several issues arising from the traffic data provided by the MNOs – in particular,

- [✂….] provided an aggregate traffic forecast up to 2021 without a split by technology; a constant growth rate of [✂….] per annum was assumed
- [✂….] only provided data from 2015 and March 2016; no forecast was provided
- [✂….] traffic was carried over [✂….]'s network; [✂….] traffic data was provided by [✂….] but no forecast was provided
- The overall traffic forecasts provided by [✂….] differ substantially in terms of growth rates per annum

As far as possible, we have used the data provided by the MNOs for the assessment model. However, a number of assumptions had to be made to address the gaps and deficiencies in the data provided in order to derive the future traffic by technology up to 2024. These are listed in Table A-3.

Table A-3: Assumptions made for each MNO to derive traffic forecasts to 2024

MNO	2G	3G	4G
[✂….]	Scaled by annual rate of decline of [✂….] using 2015 as base	Scaled by annual rate of decline of [✂….] using 2015 as base	Overall traffic derived based on latest Cisco forecasts (1) and then deduct 2G and 3G traffic
[✂….]	As provided by [✂….]	As provided by [✂….]	As provided by [✂….]
[✂….]	Scaled by annual rate of decline of [✂….] using 2015 as base	Scaled by annual rate of decline of [✂….] using 2015 as base	Overall traffic derived using annual growth rate of [✂….](2) and then deduct 2G and 3G traffic
[✂….]	As provided by [✂….]	Scaled by subscribers forecast using 2016 as base	As provided by [✂….]

Notes to Table A-3:

(1) Adjusted following discussion in June meeting; initial [✂….]'s data provided had been based on a higher growth rate of [✂….] per annum; Cisco's forecast for Japan and Korea used as proxy for Hong Kong.

(2) Based on discussions in June meeting; a growth rate of [✂….] is applied for 2016 and this declines to [✂….] by 2024.

Table A-4 shows the annual mobile traffic growth rates for each MNO based on the assumptions in Table A-3 above. The growth rates forecast by [✂….] appear to be more conservative than the other MNOs; one likely reason is that [✂….]'s subscribers are already heavy mobile data users (see Figure A-1) unlike the other MNOs which are growing from a lower traffic base per subscriber. The growth rates for [✂….] are generally aligned with those published by vendors such as Cisco[40] and Ericsson[41]. It is difficult to make direct comparisons with Cisco and Ericsson as they do not publish forecasts for Hong Kong; however, the rate of growth tends to be in the region of 30% to 40% for Western Europe and developed Asia Pacific countries. The growth rates in Table A-4 are the basis for the MNO traffic forecast used in the assessment model.

Figure A-1:

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

Table A-4: Mobile traffic annual growth rates

	2016	2017	2018	2019	2020	2021	2022	2023
MNO1	…..	…..	…..	…..	…..	…..	…..	…..
MNO2	…..	…..	…..	…..	…..	…..	…..	…..
MNO3	…..	…..	…..	…..	…..	…..	…..	…..
MNO4	…..	…..	…..	…..	…..	…..	…..	…..
Overall	41%	35%	27%	26%	25%	24%	24%	22%

[✂….]

For the sensitivity analysis an alternative forecast based on higher traffic growth rates are used as shown in Table A-5. The high traffic growth forecast applies Cisco's annual growth rates for Japan and Korea across the territory wide Hong Kong market.

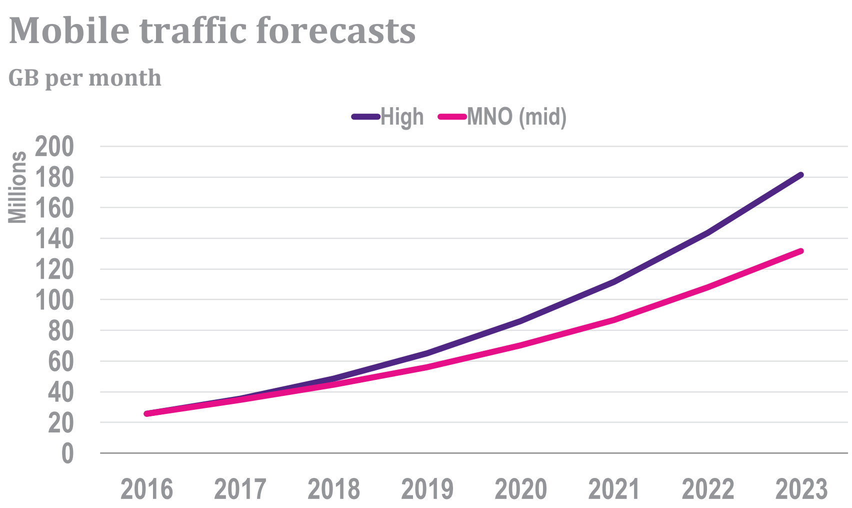
40 Cisco. Visual Networking Index. June 2016 http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/

41 Ericsson Mobility Report. June 2016 https://www.ericsson.com/mobility-report

Table A-5: Traffic forecast scenarios used for sensitivity analysis

Traffic	2016	2017	2018	2019	2020	2021	2022	2023
High	41%	39%	36%	34%	32%	30%	28%	26%
MNO (mid)	41%	35%	27%	26%	25%	24%	24%	22%

Figure A-2:



Note: Mid forecast is based on MNOs' data (adjusted)
Source: Plum Consulting, MNO data

Figure A-2 illustrates the MNO (mid) forecast used in the assessment model and the high forecasts used for the sensitivity analysis. Based on the subscribers forecast provided by the MNOs, the average monthly data consumption per subscriber will increase to 9 GB (MNO/mid) and 12.5 GB (high) in 2023[42] compared to the current average of 2 GB.

A.2 MTR information provided by MNOs

There were two rounds of information requests relating to the MTR. In the first round (April/May 2016), information was requested for the MTR IRS as a whole. This was done together as part of the data gathering exercise for the territory wide network and the busiest sites. The MTR information requested was similar to that of the overall network and busiest sites, namely voice and data traffic, base stations, frequencies deployed and frequency utilisation by technology. Both current and future data on each of these parameters was requested but the MNOs were only able to provide current information, with the exception of [✂….] which provided both current and future information.

[42] These values are consistent with forecasts from equipment vendors such as Ericsson and Cisco.

The second round of information request was sent to the MNOs in July 2016. The focus was on current traffic (voice and data) and the infrastructure and frequencies deployed in the next 10 busiest MTR stations[43] which were not part of the Phase 1 and Phase 2 upgrade programme involving the 18 busiest stations. All four MNOs responded with the requested information.

[43] These were identified as [✂….].

Appendix B: Description of the assessment model

B.1 Assessment model

A spreadsheet model is prepared to assess the relative impact on service quality of various radio spectrum re-assignment options in the 900 MHz and 1800 MHz bands. Service quality in a mobile data network is typically considered in terms of the data rates that can be delivered to end-users at the busiest times, although other factors such as latency are also relevant. It is not practical to estimate such parameters directly in absolute terms without having comprehensive knowledge of individual network configurations, subscriber traffic profiles and distribution of traffic across the network, all of which are subject to change over time and would require access to detailed network planning parameters that are beyond the scope of the current Study.

However, service quality as defined in the above terms is to a large extent inversely correlated with the level of traffic load across a mobile network (in the sense that service quality will be affected progressively once the design network cell loading is exceeded). The relative service quality can therefore be assessed by considering the network traffic load under various market and spectrum assignment scenarios and comparing this with the network capacity. The assessment model therefore uses traffic and infrastructure data provided directly by the MNOs to compare the likely busy hour traffic load on the network over time, for a set of spectrum and market scenarios.

The key input data for the model comprises numbers of base station sectors (outdoor and indoor), historic and projected traffic levels for each technology (2G, 3G and 4G), current and future spectrum holdings in each mobile frequency band and the projected market shares for the four MNOs under the various identified scenarios. The model will also accommodate a new entrant to the market at the time spectrum re-assignment occurs and it can adjust assignments for the four MNOs to provide spectrum for the new entrant. The assessment model will accommodate different assumptions for RFR spectrum.

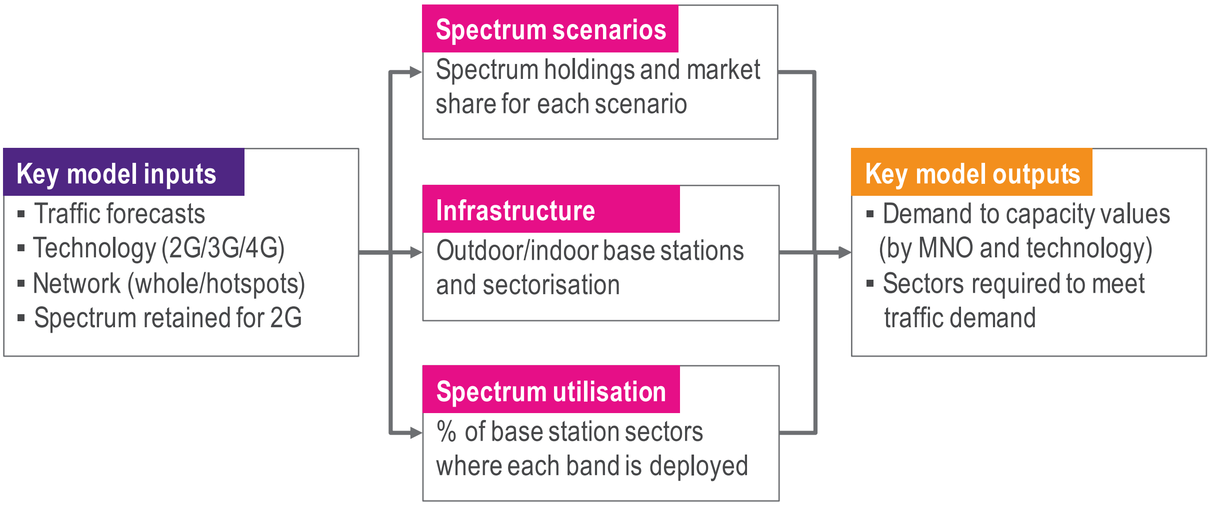
Additional inputs are also required, such as assumed spectrum efficiency and whether and when other existing bands such as 850 MHz and 1.9 – 2.2 GHz will be refarmed.

The principal output of the model is the comparison of traffic demand to network capacity using a metric called Demand Capacity Overage. The model provides the flexibility to compare the demand and capacity over time between different spectrum and market scenarios for a specific MNO, or between MNOs for a specific spectrum and market scenario.

B.2 Assessment model schematic

Figure B-1 shows the schematic of the assessment model.

Figure B-1:



There are a number of parameters that can be set by the user as shown in the key model inputs box. Using this information and parameters pre-set in the model (such as spectrum efficiency for each technology type) the model calculates the demand profile for each MNO and the capacity provided by the infrastructure / spectrum available. It then compares these outputs to produce relevant outputs. It also calculates, based on demand, the capacity in terms of number of sectors required to serve the demand. This function can be useful where the DCO exceeds the threshold as it provides insight into how much more infrastructure is required to support demand.

It should be noted that the model treats spectrum in the 900 MHz and 1800 MHz bands in the same way. For example, it assumes that the same spectrum efficiency assumptions apply to both bands.

B.3 Model outputs

The assessment model can deliver outputs in tabular or graphical format. There are two categories of output data, one comprising a comparison of the impact of each market and spectrum scenario on the selected MNO (or on the market as a whole) and the other comparing the impact of a given scenario on each of the four existing MNOs.

B.3.1 Supplementary output data

A number of other outputs are generated, which are intended mainly to aid understanding of the differences between the scenarios and to act as a cross check on the outputs. These include:

- Projected network busy hour data rate and capacity of existing network infrastructure (Gbps)
- Subscribers (all networks, millions)
- Monthly data traffic on each network
- Data traffic per subscriber on each network
- Sectors required to support expected traffic level for selected MNO

B.4 Limitations of the assessment model

The assessment model provides an estimate of network performance. It does this by calculating a view of supply and demand and comparing the two to assess network loading. It should be noted that the model is not a simulation or emulation of the network and that there will be limits to its accuracy as a result. However, its application to a network of the size of Hong Kong with a large number of subscribers and infrastructure nodes allows simplifying assumptions and generic parameters to be used with a reasonable degree of confidence. Use of data supplied by the MNOs, especially for supply side factors, helps with this.

Performance of a real network can be much more variable than the assessment model demonstrates. There may, for example, be short term peaks of traffic that are far higher than the busy hour hot spot performance calculated in the assessment model. The only way to accurately account for such phenomena would be to use a network simulation running multiple demand scenarios. The accuracy of the assessment model will also decrease as the scenario being modelled becomes smaller and more specific. The model is not designed for the analysis of a situation where there are only a small number of cells/sectors as the validity of the simplifying assumptions will be questionable for something this granular. In such circumstances the use of a different model or network simulation is recommended.

Appendix C: Spectrum holdings by scenario

The following tables show the spectrum deployed by MNO by technology for each scenario. These reflect the refarming assumptions discussed in Section 3.5.4 above.

C.1 Scenario 1 – Base case (status quo) – No change in current assignments

Table C-1: Scenario 1 [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-2: Scenario 1 [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-3: Scenario 1 [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-4: Scenario 1 [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-5: Scenario 1 (all MNOs)

	2016	2017	2018	2019	2020	2021	2022	2023
2G	.....	.....	.....	.....	.....	.....	.....	.....
3G	.....	.....	.....	.....	.....	.....	.....	.....
4G (FDD)	.....	.....	.....	.....	.....	.....	.....	.....
4G (TDD)	.....	.....	.....	.....	.....	.....	.....	.....

C.2 Scenario 2 – Spectrum re-assigned in current proportions but defragmented

Table C-6: Scenario 2 [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-7: Scenario 2 [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-8: Scenario 2 [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-9: Scenario 2 [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-10: Scenario 2 (all MNOs)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.3 Scenario 3 – Spectrum re-shuffling among incumbent MNOs involving 2×20 MHz of spectrum in total

Table C-11: Scenario 3 [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-12: Scenario 3 [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-13: Scenario 3 [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-14: Scenario 3 [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-15: Scenario 3 (all MNOs)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.4 Scenario 4 – Spectrum re-shuffling among incumbent MNOs involving 2×15 MHz of spectrum in total

Table C-16: Scenario 4 [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-17: Scenario 4 [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-18: Scenario 4 [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-19: Scenario 4 [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-20: Scenario 4 (all MNOs)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	.....	.....	.....	.....	.....	.....	.....	.....
3G	.....	.....	.....	.....	.....	.....	.....	.....
4G (FDD)	.....	.....	.....	.....	.....	.....	.....	.....
4G (TDD)	.....	.....	.....	.....	.....	.....	.....	.....

C.5 Scenario 5 – Spectrum assignments reflect MNO market share

Table C-21: Scenario 5 [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-22: Scenario 5 [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....

	2016	2017	2018	2019	2020	2021	2022	2023
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-23: Scenario 5 [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-24: Scenario 5 [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-25: Scenario 5 (all MNOs)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.6 Scenario 6A – New entrant acquires 2×20 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]

Table C-26: Scenario 6A [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-27: Scenario 6A [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-28: Scenario 6A [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-29: Scenario 6A [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-30: Scenario 6A (all MNOs, excluding new entrant)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	.....	.....	.....	.....	.....	.....	.....	.....
3G	.....	.....	.....	.....	.....	.....	.....	.....
4G (FDD)	.....	.....	.....	.....	.....	.....	.....	.....
4G (TDD)	.....	.....	.....	.....	.....	.....	.....	.....

C.7 Scenario 6B – New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]

Table C-31: Scenario 6B [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-32: Scenario 6B [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....

	2016	2017	2018	2019	2020	2021	2022	2023
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-33: Scenario 6B [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-34: Scenario 6B [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-35: Scenario 6B (all MNOs, excluding new entrant)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	.....	.....	.....	.....	.....	.....	.....	.....
3G	.....	.....	.....	.....	.....	.....	.....	.....
4G (FDD)	.....	.....	.....	.....	.....	.....	.....	.....
4G (TDD)	.....	.....	.....	.....	.....	.....	.....	.....

C.8 Scenario 6C – New entrant acquires 2×15 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]

Table C-36: Scenario 6C [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-37: Scenario 6C [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-38: Scenario 6C [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....
LTE900	.....	.....	.....	.....	.....	.....	.....	.....
GSM1800	.....	.....	.....	.....	.....	.....	.....	.....
LTE1800	.....	.....	.....	.....	.....	.....	.....	.....
UMTS2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2100	.....	.....	.....	.....	.....	.....	.....	.....
LTE2300	.....	.....	.....	.....	.....	.....	.....	.....
LTE2600	.....	.....	.....	.....	.....	.....	.....	.....

Table C-39: Scenario 6C [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	.....	.....	.....	.....	.....	.....	.....	.....
LTE850	.....	.....	.....	.....	.....	.....	.....	.....
GSM900	.....	.....	.....	.....	.....	.....	.....	.....
UMTS900	.....	.....	.....	.....	.....	.....	.....	.....

	2016	2017	2018	2019	2020	2021	2022	2023
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-40: Scenario 6C (all MNOs, excluding new entrant)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.9 Scenario 6D – New entrant acquires 2×10 MHz currently held by [✂….]

Table C-41: Scenario 6D [MNO1]

HKT	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-42: Scenario 6D [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-43: Scenario 6D [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-44: Scenario 6D [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-45: Scenario 6D (all MNOs, excluding new entrant)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.10 Scenario 6E – New entrant acquires 2×10 MHz currently held by [✂….], 2×5 MHz currently held by [✂….], 2×5 MHz currently held by [✂….]; [✂….] acquires 2×5 MHz currently held by [✂….]

Table C-46: Scenario 6E [MNO1]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-47: Scenario 6E [MNO2]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-48: Scenario 6E [MNO3]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-49: Scenario 6E [MNO4]

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Table C-50: Scenario 6E (all MNOs, excluding new entrant)

All MNOs	2016	2017	2018	2019	2020	2021	2022	2023
2G	…..	…..	…..	…..	…..	…..	…..	…..
3G	…..	…..	…..	…..	…..	…..	…..	…..
4G (FDD)	…..	…..	…..	…..	…..	…..	…..	…..
4G (TDD)	…..	…..	…..	…..	…..	…..	…..	…..

C.11 Mitigating scenarios

MNO2 faces potential service quality issues with its 3G network (all scenarios) and its 4G network (Scenario 6B). One of the potential mitigation for the 3G service quality issues is to delay the refarming of spectrum in the 1.9 – 2.2 GHz band for 4G as discussed in Section 4.5.2. The spectrum holdings for MNO2 in this situation is shown in Table C-51.

Table C-51: MNO2 – mitigation (delayed refarming of 1.9 – 2.2 GHz to 2022)

	2016	2017	2018	2019	2020	2021	2022	2023
UMTS850	…..	…..	…..	…..	…..	…..	…..	…..
LTE850	…..	…..	…..	…..	…..	…..	…..	…..
GSM900	…..	…..	…..	…..	…..	…..	…..	…..
UMTS900	…..	…..	…..	…..	…..	…..	…..	…..

	2016	2017	2018	2019	2020	2021	2022	2023
LTE900	…..	…..	…..	…..	…..	…..	…..	…..
GSM1800	…..	…..	…..	…..	…..	…..	…..	…..
LTE1800	…..	…..	…..	…..	…..	…..	…..	…..
UMTS2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2100	…..	…..	…..	…..	…..	…..	…..	…..
LTE2300	…..	…..	…..	…..	…..	…..	…..	…..
LTE2600	…..	…..	…..	…..	…..	…..	…..	…..

Appendix D: MNO specific DCO results

D.1 MNO1

Table D-1: MNO1 – 2G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-2: MNO1 – 2G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-3: MNO1 – 3G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-4: MNO1 – 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-5: MNO1 – 4G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-6: MNO1 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.6%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-7: MNO1 – all technologies, territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-8: MNO1 – all technologies, high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

D.2 MNO2

Table D-9: MNO2 – 2G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-10: MNO2 – 2G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-11: MNO2 – 3G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-12: MNO2 – 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%

Table D-13: MNO2 – 4G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-14: MNO2 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-15: MNO2 – all technologies, territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-16: MNO2 – all technologies, high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

D.3 MNO3

Table D-17: MNO3 – 2G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-18: MNO3 – 2G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-19: MNO3 – 3G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-20: MNO3 – 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-21: MNO3 – 4G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-22: MNO3 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-23: MNO3 – all technologies, territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-24: MNO3 – all technologies, high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

D.4 MNO4

Table D-25: MNO4 – 2G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-26: MNO4 – 2G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-27: MNO4 – 3G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-28: MNO4 – 3G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-29: MNO4 – 4G territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-30: MNO4 – 4G high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-31: MNO4 – all technologies, territory wide – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D-32: MNO4 – all technologies, high traffic areas – DCO

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Scenario	2016	2017	2018	2019	2020	2021	2022	2023
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix E: Summary of the feedback of the MNOs and the MTRC (September 2016 meetings)

The points set out below reflect the key issues raised in Plum's meetings with the MNOs and the MTRC that took place in the week of 5 September 2016.

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