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SMALL CELL COST SHARING

(FULL REPORT)

Small cell cost sharing - full report

by NGMN Alliance

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Abstract

There is a long held vision of very high capacity networks using small cells in areas of high demand. With the expected availability of large quantities of mmWave spectrum for 5G, this opportunity in principle becomes even greater. But the economics of small cell deployment have proved very challenging in practice – and this challenge will only increase at mmWave frequencies, where coverage of an individual cell is typically even smaller. Unless the industry can find ways to reduce the per cell building, operation and maintenance costs, the opportunity to build out small cell networks using mmWave spectrum will be severely constrained.

This NGMN report aims to identify and assess different approaches to improving the economics of small cells through some form of cost sharing between operators (with 5G small cells possibly anchored to an LTE coverage layer). This study considers different economic models (including such as independent "neutral host" or jointly owned infrastructure companies) as well as technology aspects.

Document History

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13/09/2019	V 0.1	Steve Babbage, Vodafone	Initial draft (based on NGMN internal report)
18/09/2019	V0.2	Steve Babbage, Vodafone	Added text based on suggestions from TELUS to clarify expectations on regulators
16/10/2019	V0.3	Jean-Yves Bernard, Rogers; Steve Babbage, Vodafone	Changes based on comments from Rogers
21/10/2019	V0.4	Steve Babbage, Vodafone	Slight change to some diagrams, one new reference added, and some text made more suitable for an external report
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20/12/2019	V1.1	Steve Babbage, Vodafone	One sentence added in section 2.1 to clarify which architectures are in scope. Also added a relevant reference.

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GLOSSARY

Abbreviation	Meaning
BBU	Baseband Unit
CEPT	European Conference of Postal and Telecommunications Administrations
CPRI	Common Public Radio Interface
CU	Central Unit (in a split gNodeB architecture)
DAS	Distributed Antenna System
DCU	Data Concentrating Unit
DIS	Digital Indoor System
DU	Distributed Unit (in a split gNodeB architecture)
EN-DC	E-UTRA – NR Dual Connectivity
eNB	Evolved NodeB (which could be a Next Generation eNB, or ng-eNB)
EPC	Enhanced Packet Core
e-UTRA	Evolved Universal Terrestrial Radio Access
gNB	Next Generation NodeB
MIMO	Multiple Input, Multiple Output (antenna)
MNO	Mobile Network Operator
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator Radio Access Network
NGCN	Next Generation Core Network
NR	(5G) New Radio
PCI	Physical Cell ID
PLMN	Public Land Mobile Network
pRRU	Pico-RRU
RF	Radio Frequency
RRH	Remote Radio Head
RRU	Remote Radio Unit
UE	User Equipment

Contents

1 INTRODUCTION AND MOTIVATION

1.1 Background

There is a long held vision of very high capacity networks using small cells in areas of high demand. With the expected availability of large quantities of mmWave spectrum for 5G, this opportunity in principle becomes even greater. But the economics of small cell deployment have proved very challenging in practice – and this challenge will only increase at mmWave frequencies, where coverage of an individual cell is typically even smaller. Unless the industry can find ways to reduce the per cell building, operation and maintenance costs, the opportunity to build out small cell networks using mmWave spectrum will be severely constrained.

Whilst this paper focuses on how various forms of sharing can reduce the costs of small cells deployment, it should be noted that there are other barriers to small cells deployment today, both technical and commercial. These include planning permission, and potentially prohibitive costs of accessing tower company assets or Government owned assets where such parties may want to extract value from the delivery process. The need to address some of the barriers to small cell deployment is recognised by regulators, for example in Europe where the European Electronic Communications Code agreed in 2018 includes specific provisions (see Article 57 of [3]) aimed at facilitating small cells deployment. Other national initiatives have also looked at how barriers can be reduced, such as the UK Government's barrier busting task force and regulatory reforms to enhance the powers of operators in relation to rights to deploy of mobile infrastructure.

1.2 Aim of this study

This NGMN project aims to identify and assess different approaches to improving the economics of small cells through some form of cost sharing (with 5G small cells possibly anchored to an LTE coverage layer). This study considers different economic models (including such as independent "neutral host" or jointly owned infrastructure companies) as well as technology aspects.

1.3 Structure of this report

Chapter 2 describes the use cases and architectures of interest. Chapter 3 explains what we believe the role of regulators should be in the kinds of cost reduction we are discussing in this. Chapter 4 lists the criteria against which possible approaches should be evaluated. Chapter 5 identifies possible cost reduction approaches – both the technical / physical approaches and (where these are not obvious) associated economic models to create suitable incentives both for companies building sites and for other companies taking advantage of those sites. In chapter 6, identified alternatives are evaluated against the selected criteria. Conclusions are drawn in chapter 7.

2 USE CASES

2.1 Deployment architectures

The small cell deployment use cases that we consider in this document are illustrated in Figure 1. Note that the dual connectivity architectures we focus on are those in which the secondary cell is a gNodeB, operating in high frequency 5G spectrum; architectures in which the secondary cell is an LTE eNodeB, such as Option 4 or LTE-only dual connectivity, are out of scope [14].

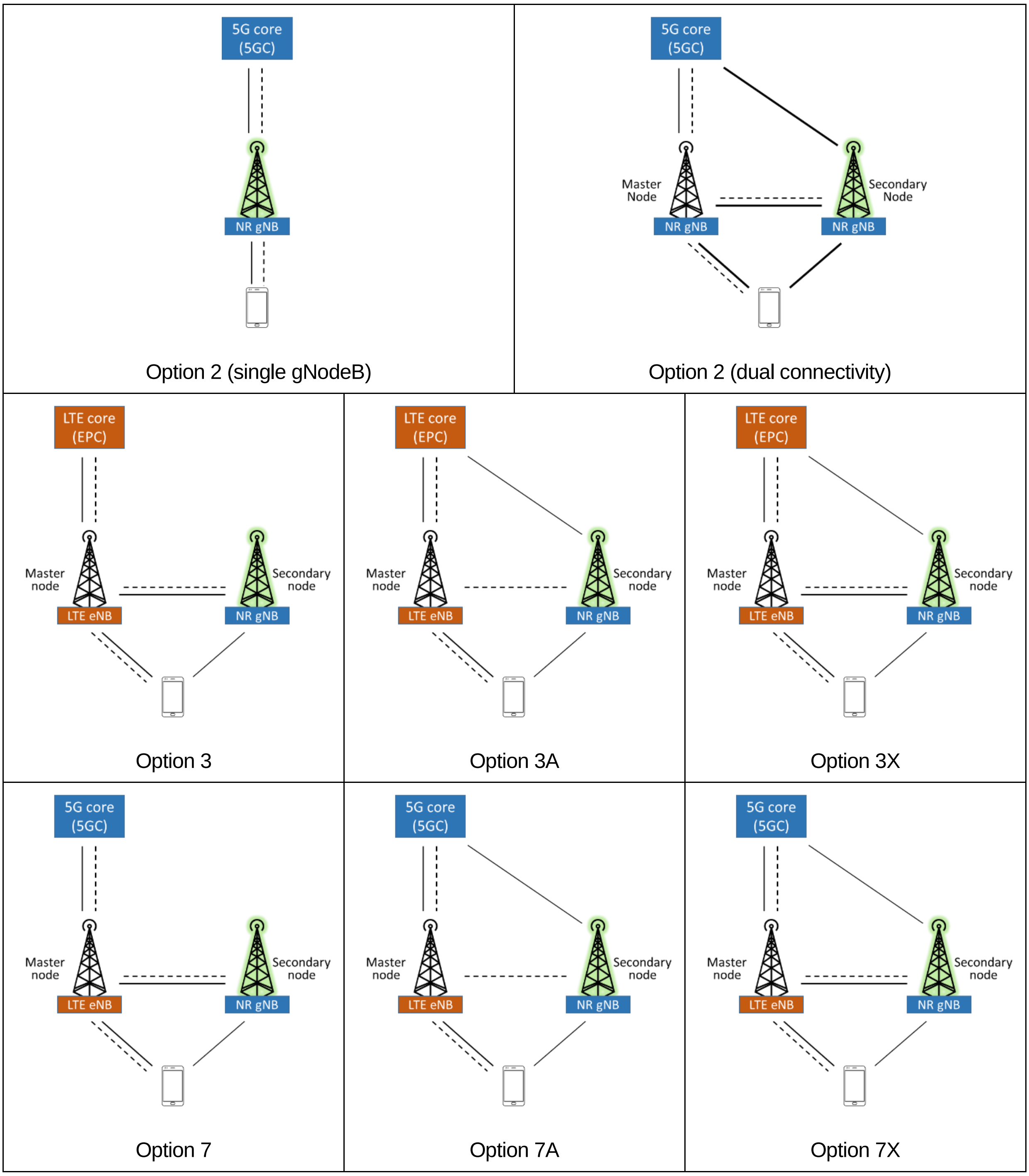

Figure 1: Small cell deployment architectures. (The high frequency small cell is coloured green. User plane traffic is shown by a solid line, and control plane traffic by a dashed line.)

The picture in the top left shows a small cell deployed on its own. This will only work well in a limited set of circumstances, e.g. where mobility is not expected.

All other pictures show a high frequency (e.g. mmWave) small cell used as a secondary cell in conjunction with a lower frequency “anchor layer” master cell. Typically most of the user traffic volume will be carried by the small cell, while the master cell will provide coordination and mobility, and fill in the gaps between small cells.

It will be seen that in some architectures the traffic from the small cell is backhauled entirely via the master cell (over the X2 or Xn interface between the two cells), while in others the small cell has its own direct backhaul link. Option 2 (dual connectivity) is shown as a single picture, but in principle the same backhauling options are possible: exclusively via the master cell (like options 3 and 7), or exclusively via a direct connection to the core (like options 3A and 7A), or a combination of both (like options 3X and 7X).

Where there is a master cell and a secondary cell, we would usually expect them to belong to the same mobile operator. But later in this document we will consider approaches where they belong to different operators. A typical (non-roaming) example of this would be as follows:

- the core network and the master cell belong to the customer's home MNO;
- the secondary small cell is run by a different company;
- user plane traffic is backhauled entirely via the master cell, as in options 3 or 7 (so there is no direct interface between secondary cell and core).

Examples of such an approach are illustrated in Figure 2.

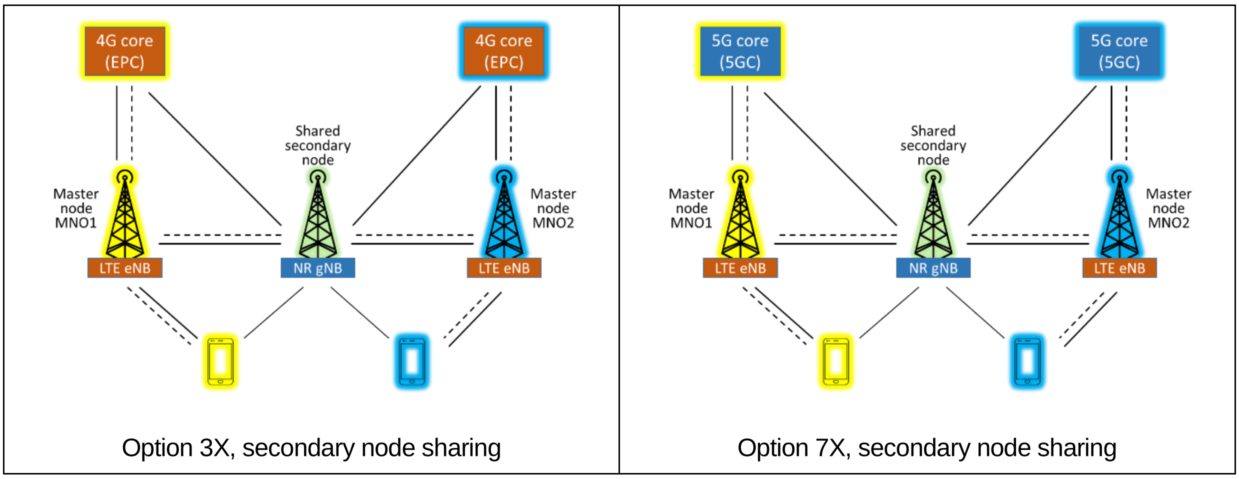

Figure 2: Secondary node shared between two MNOs

Finally, we should note that the split gNodeB architecture may be used, as illustrated in Figure 3.

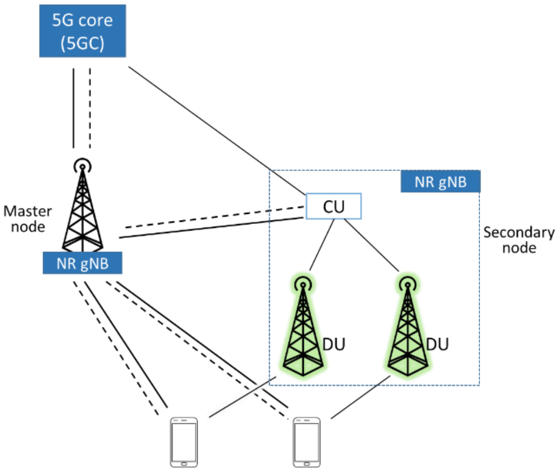

Figure 3: Split gNodeB architecture (CU = Central Unit, DU = Distributed Unit)

2.2 Spectrum availability

The main focus of this paper is on mmWave small cells, although some aspects apply to lower frequency small cells too. In Europe, we may reasonably expect at least 1GHz of spectrum to be available in the 26GHz band (this is what has already been made available through auction in Italy), and eventually several GHz. Similarly, in other regions, mmWave spectrum including the 28GHz band is being made available, and in most countries we can expect at least 1GHz of it. Currently standardised mmWave bands are shown in Table 1 from 3GPP TS 38.101-2 [6].

Operating Band	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex Mode
	F_{UL_low} – F_{UL_high}	F_{DL_low} – F_{DL_high}	
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	27500 MHz – 28350 MHz	TDD

Table 1: NR bands in mmWave spectrum (from [6])

The maximum single channel bandwidth standardised in [6] is 400MHz. Inter-band carrier aggregation allows up to 1200MHz aggregated bandwidth by aggregating three 400MHz channels ([6], table 5.3A.4-1).

3 THE ROLE OF THE REGULATOR

3.1 Regulator role in cost reduction initiatives

Many factors will influence the potential and nature of small cell deployment in a particular market. We expect that different cost reduction solutions will work best in different markets, so this report will not identify a “one size fits all” approach.

We believe that the entities best placed to determine what cost reduction arrangements will work best in a market are the operators in that market. Given the economic challenges to small cell deployment that motivate this report (see section 1.1), we encourage regulators to support any solutions that the operators select, unless they see something in them that would be significantly damaging to the market. “Support” here will sometimes just mean “approve”, and sometimes mean “facilitate”, depending on the cost reduction arrangement in question.

For the avoidance of doubt: we do not believe that a regulator should impose a particular cost reduction or sharing arrangement against the best advice of the operators.

3.2 Other regulatory action to support small cells

We note that the European Union is working to reduce other barriers to small cell deployment, in the form of planning permission and permits [12]. Although this is outside the scope of the present report, we applaud this initiative and encourage regulators in other regions to take similar steps.

4 EVALUATION CRITERIA FOR COST REDUCTION ALTERNATIVES

4.1 Criterion 1: Cost per MNO per site that their customers can use

An operator may be able to use a site because they have deployed the site themselves, on their own or jointly; or because they have some sort of sharing agreement allowing some sort of access to sites built by others; or through a roaming agreement; or perhaps in other ways. In all cases, the operator’s service proposition is enhanced because their customers benefit from the coverage and capacity that the site enables.

4.2 Criterion 2: MHz of spectrum per customer served

Having access to more spectrum, e.g. through a spectrum sharing deal, may allow better service to customers without much extra cost. On the other hand, if two or more operators have to serve their customers using only the spectrum licensed by one operator, then the service to each customer may be somewhat worse.

We consider this less significant than Criterion 1, because we anticipate that even the smallest allocation of spectrum in mmWave bands will be quite large (e.g. 200MHz) – and having access to 200MHz on two sites will probably provide a lot more value than having access to 400MHz on one site.

4.3 Criterion 3: Incentives to build sites

In any cost reduction / sharing scheme, it is important that there is still a good incentive to build new sites. This could fail if the operator gains just as much benefit from roaming onto someone else's site as they do from deploying a new site, without the cost of deployment – and then every operator ends up waiting for other operators to do the building.

4.4 Criterion 4: Ability to differentiate

If every operator's customers have the same level of access to every site, then there may be no effective differentiation in service offering with respect to small cell coverage.

It is useful to distinguish between

- Criterion 4.a: differentiation in terms of sites and bandwidth
- Criterion 4.b: differentiation in terms of services offered on a particular site

How much the lack of differentiation troubles regulators will probably depend on how big a part small cells play an operator's overall service offering. If most traffic is carried on small cells, and if there is little differentiation in the small cell service offered by different operators, regulators may be concerned about ineffective competition. If most traffic is carried on other cells, then a similarity in small cell service may be less of an overall concern.

4.5 Criterion 5: Ease of operation / seamlessness

Most cost sharing approaches will probably be straightforward and unproblematic, but some could be less so. For instance, if one operator is allowed to use another operator's spectrum as long as they don't interfere, then avoiding interference may require some care, and a dispute process may be needed.

4.6 Criterion 6: Requirement for new technology

Some sharing approaches might require the development of new technology to enable the sharing.

4.7 Criterion 7: Requirement for regulatory support

Some sharing approaches might require support from telecoms regulators or modifications to licence conditions.

Overly restrictive regulatory regimes can significantly contribute to the small-cell cost of deployment, and we would like to encourage streamlined regulatory policies where possible.

4.8 Criterion 8: Meeting MNO coverage and capacity needs

Are the cells going exactly where the operator most needs them? Or is the operator having to accept cell site choices made by others, or in compromise with others?

4.9 Other possible criteria

Other criteria for evaluation could be a coverage criterion (cost per square metre covered) or a capacity criterion (cost per megabyte able to be delivered). However, both of these are largely determined by other criteria mentioned earlier in this section. For instance, cost per square metre will be closely correlated to cost per site

(Criterion 1), with some influence also from higher bandwidths (Criterion 2) leading to larger cell sizes, and from cost overheads (Criteria 5 and 6). We consider that the set of criteria identified above is sufficient for a general-purpose comparative assessment of different approaches.

5 COST REDUCTION ALTERNATIVES

5.1 Alternative 1: Share the physical site and mast, but with own electronics and own licensed spectrum

This allows sharing of the geographical site, with its power supply and physical mast. Each operator deploys all of their own "electronics", i.e. baseband units (BBUs), remote radio heads (RRHs) and antennas[1]. Some sharing of backhaul connectivity may also be possible (variants of this can be identified as sub-alternatives if need be) – see section 5.7.

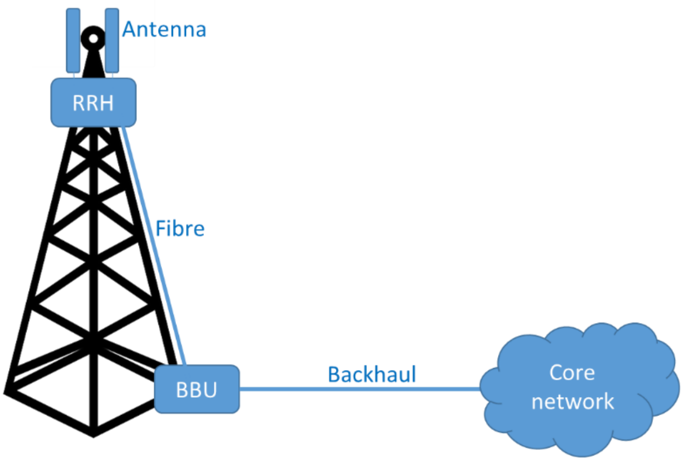

Figure 4: Base station components

Two operators may install separate antennas on the site. For FDD communication, the following minimum separation distances will maintain sufficient de-coupling between the antennas:

- either a horizontal separation > 2.0 m
- or a vertical separation > 0.5 m.

This prevents transmission from one antenna from interfering with reception at the other. There is a slight variation in the required separation distances between different frequency bands, but the recommendations given above should be suitable for any band. (These recommendations are based on proprietary analysis carried out by Orange – there is no public reference.) For synchronised TDD communication, there is no risk of transmission from one antenna interfering with reception at the other, and so this minimum separation does not apply.

Frame synchronisation may also be a constraint. We expect CEPT to publish some draft guidance on synchronization in the 3.5GHz band, for public comments, in the near future, and similar guidance for mmWave bands is likely to follow in due course.

We may distinguish four sub-alternatives here, in terms of how decisions about cell sites are made and the financial relationship between the sharing operators:

- Alternative 1.a: one (host) operator acquires access to the site, and then other (tenant) operators lease access from the host.

[1] In this document we generally use the terminology of separate RRHs and antennas, but with newer active antenna designs the two are effectively integrated.

- Alternative 1.b: the operators collaborate to acquire sites as a collective.
- Alternative 1.c: a “Towers” company, independent of the mobile operators, acquires access to the site and builds the mast; individual operators lease access and mount their own antennas.
- Alternative 1.d: the “Hong Kong Model”, where:
  - operators collectively agree where new sites should be built;
  - for each site, a “lowest bidder wins” auction determines which operator will act as host, building and equipping the site;
  - whichever other operators choose to lease access to that site pay their share of the host’s costs for the shared elements of the site. See section 5.9 for a fuller explanation.

There are no technical differences between these two sub-alternatives, but the incentives and financial arrangements (and possibly also the regulatory considerations) may be different.

5.2 Alternative 2: Share site and electronics, but using own licensed spectrum

The operation of the site itself would typically be by one “host” operator, with the others as “tenants”; or it could be a joint operation between the participants. As for Alternative 1, we can separate these as four sub-alternatives:

- Alternative 2.a: one (host) operator acquires access to the site, and then other (tenant) operators lease access from the host.
- Alternative 2.b: the operators collaborate to acquire sites as a collective.
- Alternative 2.c: a “Towers” company, independent of the mobile operators, acquires access to the site and erects the mast and electronics; individual operators lease access.
- Alternative 2.d: the “Hong Kong Model”, as described in the previous section.

There are potentially also multiple different possible variants of sharing electronics:

i. Share BBU, but completely separate RRHs and antennas
ii. Share BBU, but separate individual antennas within a MIMO panel (note: this is broadly equivalent to variant i, but applied to a different antenna type)
iii. Share BBU, share RRHs and antennas (but still separate spectrum)
iv. Separate BBUs, but share RRHs and antennas (but again, still separate spectrum)

… although variant iv is, to our knowledge, not supported by equipment today.

Sharing the electronics, but with each operator in its own distinct frequency, is a recognized arrangement called Multi-Operator Radio Access Network (MORAN).

Some sharing of backhaul connectivity may also be possible (variants of this can be identified as sub-alternatives if need be) – see section 5.7.

5.3 Alternative 3: National roaming between operators

We assume that operators would want only limited national roaming – only on certain cells, or perhaps only in a certain frequency band – rather than full national roaming across the entire network.

Technically, it is perfectly feasible to support national roaming only on certain cells or location areas. The roamed-to operator will be on the device’s permitted roaming list; when the device requests to roam onto a cell for which national roaming is not supported, the network will reject the request. However, depending on which cells do and don’t allow national roaming, this could lead to quite a lot of rejections. One possibility would be to use a separate PLMN ID for the sites allowing national roaming; then devices would request to roam onto that PLMN only, and not onto the operator’s other cells.

5.4 Alternative 4: "Towers" company builds sites and "owns" spectrum, operators roam on

With this alternative, one entity controls spectrum and builds sites that are then accessed by multiple operators. (There could potentially be more than one such company, if this creates useful competition that motivates site roll-out.)

Two factors then determine variants of this alternative:
- which operators can access which site;
- how the company determines where to build new sites.

These are identified in sub-sections below.

5.4.1 Which operators can access which sites

Options for this include:
1. Automatic access to all sites for all participating licensed operators
2. Operators pay for access to individual sites

5.4.2 How the "towers" company determines where to build new sites

Options for this include:
(a) Towers company makes its own choices, builds where it thinks it can attract MNOs
(b) MNOs are shareholders in towers company, and influence new site decisions that way
(c) MNOs pay to prioritise their preferred locations (or an interested third party, e.g. a stadium owner, could pay to prioritise a location)

5.4.3 Labelling of variants

Based on the lists in the previous two sections, variant alternatives are identified as for example
- **Alternative 4.1.a**: Automatic access to all sites for all participating licensed operators; towers company makes its own new site choices, builds where it thinks it can attract MNOs
- **Alternative 4.2.b**: Operators pay for access to individual sites; MNOs are shareholders in towers company, and influence new site decisions that way

and similarly for all combinations of list elements from the previous two sections.

5.5 Alternative 5: Share spectrum

There are many different possible approaches to sharing spectrum (see for instance [1], clause 221). We do not attempt to provide an exhaustive list of approaches here – there are too many – but we can split the approaches into two broad categories, as per the following two subsections.

5.5.1 Using spectrum when others aren't using it

Examples of this approach include:
- **Alternative 5.1**: A licensee may allow other licensees access to her frequencies, either on wholesale terms or for free, in areas where she is not using those frequencies herself[2]. For example, if operators A and B have licensed 200MHz each, A can use the full 400MHz on one of her cells if that cell doesn't interfere with any cell belonging to B. An example of this approach can be seen in the licence conditions for the 26.5 – 27.5GHz band in Italy. In principle, this allows operators to provide higher bandwidth and/or capacity (and possibly slightly increased coverage) in an opportunistic way, without impacting each other's customers. In terms of cost reduction, there is a small potential benefit from the increased coverage area; or if demand were very high, it could allow one cell to serve an area where otherwise two would have been needed.

  Any use of another licensee's spectrum may be time limited, if that licensee later claims it back.

[2] It was a condition of the 26GHz licences auctioned in Italy in 2018 that licensees offer access on this basis.

From the customer's perspective, having this additional spectrum provided and then taken away may create a worse perception than not having it in the first place.

In practice, managing the sharing may also be tricky, with licence owners likely to focus on safeguarding their own service offerings more than on opening up to others. Management of spectrum access (avoiding interference) could be done using a combination of site-and-spectrum databases and geolocation as is typically recommended for Licensed Shared Access, or using structured coordination techniques similar to those used for Licensed Assisted Access, or possibly using more dynamic listen-before-talk mechanisms. Any of these management solutions will involve costs, which will have to be weighed against any benefit achieved.

5.5.2 Using spectrum simultaneously

Examples of this approach include:

- **Alternative 5.2**: Two or more operators may pool their spectrum at a single site. This could be done in conjunction with MOCN sharing (see section 5.6), or with national roaming (MNO A operates the site, MNO B's customers roam on). As long as demand is not too high, the increased total spectrum could be used to achieve a slightly increased coverage area and thus serve a slightly greater number of customers.

- **Alternative 5.3:** Licensees could agree voluntarily to pool their spectrum as a condition of participation in a wider small cell sharing agreement. This could be done in several possible ways:

  i) Operators acquire licences to spectrum in a conventional way, and then allow the spectrum to be used by a single "towers" company; or by each party deploying sites, if there are multiple such parties involved in the agreement. This has the advantage that the towers company or deploying companies can potentially use any available spectrum in the band. They could perhaps deploy all the bandwidth at every site, but at ≈ 1 GHz that would exceed the bandwidth spanned by a single radio-head, and so would require multiple radio-heads at each site, which would be expensive.

     In the shorter term, when capacity needs are lower, the company or companies could say deploy 200-400 MHz at each site, while adopting a frequency re-use pattern that allows higher power at individual sites while minimising interference between sites. This would lead to fewer sites overall, and have the advantage that all participating operators could use the same frequencies within the span of a single radio-head at every site, regardless of whether it was originally "their" spectrum. Also, by adopting a frequency use pattern that minimises interference between sites, the spectral efficiency (in bits/sec/Hz) is increased; thus, for example, using 250MHz at each site would in practice provide more than a quarter of the capacity that could be achieved by using the same 1GHz at each site.

     A disadvantage with this approach is that operators would have less freedom to deploy their own spectrum at any private sites falling outside the agreement. It might be possible for operators to specify "exception" locations (i.e. locations of private sites) and for the towers company or companies to tune around these exceptions, but it would become difficult to manage.

  ii) Operators allow their spectrum to be pooled only at sites where the operator has agreed to participate. This would involve a more complex frequency-planning arrangement, since exception lists would need to be managed at all sites, and it might not be possible to deploy contiguous spectrum at many sites. The deployable spectrum may be fragmented and fall outside the span of a single radio-head. However the mechanism for an operator to "opt out" of sites where they are already deploying their own spectrum nearby would be fairly obvious.

- **Alternative 5.4:** The available band is partitioned into an "exclusive use" pool and a "sharing" pool. Each licensee receives a set of frequencies for exclusive usage at their own private sites, and a right to use all frequencies within the sharing pool, but with a requirement to co-ordinate with other users within the sharing pool.

If operators consider that such a partitioning arrangement is desirable, then this would require support of a regulatory authority in dividing up the spectrum into the relevant pools, and making sure the sharing pool is contiguous; however it would naturally motivate the formation of a small cell sharing agreement to manage usage of the sharing pool, and would achieve most of the advantages of case i) of alternative 5.3, while still allowing operators some private usage and differentiation outside the sharing agreement.

There may need to be a mechanism to periodically review the division of the band between the pools, to ensure that spectrum is being used efficiently.

5.6 Alternative 6: Broadcast multiple PLMN IDs

A single cell – which could be run by one of the participating operators (as in Alternative 3), or a "towers" company (as in Alternative 4) – broadcasts multiple PLMN IDs for the same frequency band, and thus allows customers of multiple operators to use the cell, each thinking that they are using their own network as usual (i.e. no roaming indicator). This alternative – sharing an antenna and sharing spectrum, and separating only in the core – is called Multi-Operator Core Network (MOCN).

We should distinguish between two cases:

- **Alternative 6.1:** Amongst participating MNOs, all spectrum in this frequency band is pooled and used for shared cells (at least within a defined region). Note: this does not rule out an MNO also launching its own unshared cell, as long as it is clearly far enough from any shared cells that there is no interference problem – this might be considered for an enterprise customer workplace, for instance.
- **Alternative 6.2:** As in Alternative 5.4, some (pooled) spectrum is used for shared cells, but also some spectrum is used exclusively by individual MNOs for their own unshared cells.

With spectrum being shared, the planning of sites needs to be coordinated across MNOs in some way. Participating MNOs can operate as some kind of collective decision making body ([8] gives a good overview of different possible approaches); as with previous alternatives, the Hong Kong model is an option, to decide who builds which site and how costs are allocated. Alternatively, cells could be built and operated by a separate TowerCo with its own allocated spectrum.

To keep our comparative analysis manageable, we enumerate the following alternatives:

- **Alternative 6.1.a:** All spectrum pooled for shared cells; cross-MNO agreement mechanism for selection of sites and who builds them
- **Alternative 6.1.b:** Spectrum allocated to TowerCo, which builds cells
- **Alternative 6.2.a:** Some spectrum pooled for shared cells, some retained for exclusive use; cross-MNO agreement mechanism for selection of shared sites and who builds them
- **Alternative 6.2.b:** Some spectrum allocated to TowerCo, which builds shareable cells; other spectrum licensed to individual MNOs for exclusive use

… but within these there are different options for how operators reach agreement, or (as for Alternative 4) different options for how the TowerCo could make its site decisions.

Regulators tend to consider MOCN as providing reduced differentiation between operators, and do not always respond positively to requests for it (see e.g. [7]); some may also be concerned that the sharing of spectrum reduces spectrum auction revenue. Nevertheless, there are several examples of MOCN in operation around the world (see [4] and [5]). If vendors implement a method of partitioning resources (e.g. DSP resources) unequally, this could retain a greater degree of competition and help to allay regulatory concerns. Approaches that also allow operators to build unshared cells may also help to address this concern.

5.7 Alternative 7: Secondary node sharing

Alternatives 1 – 6 are described in terms of individual shared cells. In practice, however, high frequency cells will very often be used in conjunction with low frequency (coverage) cells, in a dual connectivity architecture. The low frequency cell acts as the master node, and the high frequency cells form a secondary node. Of the architecture options shown in Figure 1, all apart from the first show dual connectivity.

We may then consider approaches where only the secondary node is shared. This was illustrated earlier in Figure 2: a single shared node can be used as a secondary node by the master nodes of multiple different MNOs.

The mechanism by which dual connectivity is established is in principle compatible with this secondary node sharing:

- The process by which a secondary node connection is established for a UE is controlled by the master node, and described in 3GPP TS 37.340 [9]. The master node sends signalling to the desired secondary node and to the UE in order to establish the secondary connection.
- The master node's decision to do this is typically based in part on measurements reported by the UE about the neighbouring cells that it can see. These measurements refer to a broadcast cell identifier called the Physical Cell ID (PCI), which is locally unique and which is not inherently tied to an individual PLMN.
- Thus, UEs connected to master nodes of two different operators can both report that they can see a strong signal from the same small cell (referred to by its PCI); and, if the right inter-cell interfaces are in place, both master nodes can request to add that small cell as a secondary node. We return to this procedure in section 7.2.

For Option 3 (dual connectivity between LTE master node and 5G NR secondary node, also called EN-DC) the whole procedure is shown in detail in [9].

Two approaches are possible here:

- The small cell is only accessible as a secondary node in a dual connectivity architecture – it does not permit single connectivity.
- The small cell permits either single or dual connectivity (being the secondary node in any dual connectivity). This can be seen as a combination of Alternatives 6 and 7.

5.8 Backhaul considerations

Where multiple operators share a site, they will need to backhaul at least some traffic to their own core networks. But having multiple separate backhaul connections to a site – especially fibre connections – would lose a lot of the value of sharing. Considerations here include:

- How much traffic needs to be routed back to the separate core networks? Is it possible to share the point at which most user plane traffic breaks out onto the internet?
- Is it useful to consider some kind of fibre hub, where the shared connections from multiple small cells are split off into connections back to individual operators' core networks?

It will be seen from Figure 1 in section 2.1 that the backhaul requirements vary for different deployment architectures. In some architectures, such as Option 3, the traffic from the (secondary) small cell is routed via the master cell; in others, such as Option 3A, the (secondary) small cell has its own backhaul connection to the core.

A common arrangement for shared sites is to have the site connected by dark fibre to an existing (high quality, national or regional) fibre network – which might belong to a separate fibre company or to one of the operators – and then having the individual operators lighting up separate streams along that fibre. Each operator can manage its own connection between its core network and the fibre network. Thus the sharing of backhaul is probably not much harder than the backhauling of a single unshared cell. Having said that – establishing a fibre connection to any cell (shared or not) can be expensive and challenging, and in some cases wireless solutions may be used instead for the "last mile" to the cell site.

This common fibre network approach is illustrated in Figure 5, with reference to Option 7X and a shared secondary node. Note that the Xn interface (both control plane and user plane elements) between the master and secondary nodes goes via the fibre network.

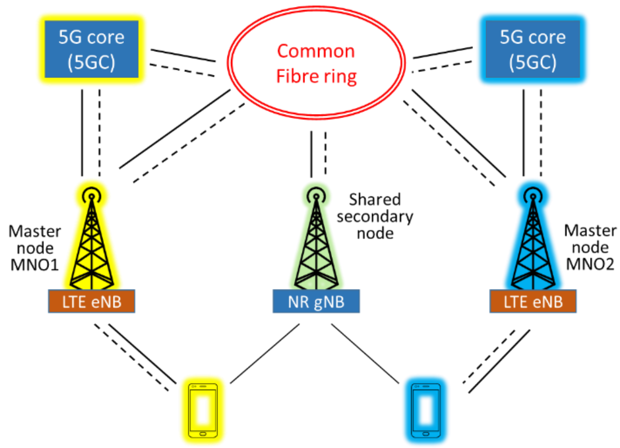

Figure 5: Backhaul and Xn interface via a fibre network (for Option 7X with a shared secondary node)

5.9 The "Hong Kong model"

The four (non-virtual) MNOs in Hong Kong have established an innovative arrangement for sharing cell sites. In section 5.9.1, we describe the context in which this arrangement operates in Hong Kong. In section 5.9.2, we describe the mechanism used for determining where cells are built, who does the building and operation, and how much the other operators pay for access; this, specifically, is what we call the "Hong Kong model" in the rest of the document. In section 5.9.3 we give some concluding remarks.

5.9.1 Indoor cells in Hong Kong

In Hong Kong, fewer than 30% of the cell sites are indoor but carrying more than 80% of the overall data traffic in the mobile network due to an extremely high population density living in an ultra-dense city. The four (non-virtual) mobile network operators in Hong Kong have therefore established a sophisticated sharing arrangement to address the high demand of indoor mobile data traffic, with the benefit of cost saving.

Historically, mobile network operators in Hong Kong have been sharing a common Distributed Antenna System (DAS) for their indoor coverage for over 20 years since the 2G era. With the development of MIMO technology starting in 4G and also upcoming high frequency band (26-28GHz) of 5G, passive sharing of DAS is no longer a technically viable solution. The indoor sharing solution has evolved into a Digital Indoor System (DIS) for active sharing of small cells.

In terms of the physical and technical sharing aspects: a state of the art Digital Indoor System is now deployed for small cell sharing among MNOs, with multiple active MIMO radio heads connected via optical fibre or ethernet to a single control unit (e.g. DCU), and each radio head shared by multiple MNOs (each using their own spectrum). MNOs can share the small cells by connecting to the single control unit with their own equipment, either by means of baseband unit inputs through CPRI interfaces, or by means of radio unit inputs through RF interfaces (which are similar to the inputs in a traditional DAS system).

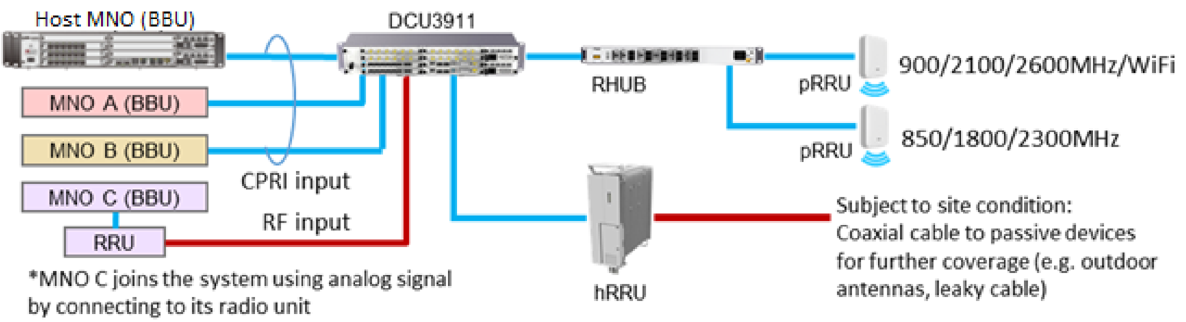

Figure 6: Connection illustration of small cell (e.g. pRRU) sharing

5.9.2 Economic and business arrangement: the "Hong Kong model"

The economic and business arrangement is of particular interest, and it is this that we refer to as the "Hong Kong model" elsewhere in this document. In Hong Kong itself, this is used specifically for indoor cells, but the same economic and business arrangement could be applied to the shared elements of an outdoor cell too. In brief:

- Two or more MNOs agree that a new site should be built in a particular location.
- Each MNO submits a bid, and the lowest bid wins; the winner becomes the "lead operator", responsible for building up the shared cell with the subsequent right of operation and maintenance.
- Any other MNOs can then obtain the right-to-use of the shared cell. To do so, they pay the lead operator a proportion of the winning bid. If all four MNOs offer the same access connectivity, then each other MNO pays the lead operator ¼ of the winning bid; the share may be different if some MNOs only use a subset of available technologies (e.g. only 4G, not 5G) or demand a different amount of bandwidth. All of the rules for determining shares are fixed in advance.
- Tenant MNOs also pay the lead operator a monthly maintenance fee (again, pre-determined).

We may illustrate this by an example. Suppose that all four MNOs (A, B, C and D) want to share a cell. MNO A believes that they can build the shared cell for €80K, but bids slightly higher than that – say €90K – to give a margin of error and to make sure that they will be happy if they end up winning. MNOs B, C and D each estimate their build costs to be €100K, so each bid at least €100K; thus MNO A's bid of €90K wins.

If all MNOs share the cell and offer the same service, then each of MNOs B, C and D pays ¼ of €90K, i.e. €22.5K, to MNO A. MNOs B, C and D are all happy to be tenants, because they're now paying €22.5K for a ¼ share of a site that would have cost them at least €100K to build. MNO A is happy to be the lead operator, because they receive €67.5K from the three tenants, and end up with a net cost of only €12.5K. Thus the incentives work for all MNOs.

In the Hong Kong model as described above, the lowest bid becomes the "winning price" in the auction, and determines what other MNOs have to pay to the lead operator. Different auction formats could alternatively be used here – see section 5.9.3.

Deciding where to build new sites is relatively straightforward. If any MNO would like to see a new site built in a particular location, they can invite the others to join a site share there as described above; if at least one other MNO agrees to share there, then the process described above can go ahead. If no other MNO is interested, the originating MNO can still go ahead and build an unshared cell if they consider it worthwhile.

5.9.3 Alternative auction formats

Consider an auction of a single item, such as a work of art. Consider an auction where each bidder submits their bid in a sealed envelope; all envelopes are then opened, the highest bid wins, and the winner pays whatever they bid.

This “sealed bid, pay as bid” auction seems simple but is in fact problematic. Suppose that I would be willing to pay up to £10m for the work of art. Should I bid £10m? If I end up winning, and the second highest bidder bid only £6m, then I have paid far more than I needed to win the item. So should I bid less? I can guess that a bid of £7m will be enough to win the item, but if someone else bids £8m I will lose the auction. So what should I do? There is no guarantee that the participant who values the artwork highest will actually win it, and it is very likely that some bidders will end up regretting their bids (i.e. wishing they had bid differently).

What happens in a classic open auction of artworks – with the auctioneer at the front with his gavel, and bids gradually increasing until only one bidder is left – is quite different from this. In that auction, I would just keep bidding until the second highest bidder (at £6m) has given up, so I might win the artwork for around £6.1m. I would only approach my limit of £10m if there is still competition in the auction.

eBay effectively works in a similar way. I place my “sealed bid”, but if I win, I don’t necessarily have to pay my full bid – I just have to pay enough to outbid the second highest bidder. This is called a second price auction, or Vickrey auction [2]. The big advantage of this auction is that my strategy is clear: I bid my full value (£10m) for the artwork. I won’t regret overbidding, because if I win, I have paid only enough to beat the second highest bidder. If someone else bids higher than I do, again I will not regret my bid, because I lose for the right reasons – not because I bid less than my full value.

Now let us apply this thinking to the Hong Kong auction, where the lowest bidder wins the auction. In the auction described in section 5.9.2, the lowest bid becomes the winning price in the auction, and determines what other operators will pay to the lead operator. This is similar to the sealed bid, pay as bid auction. Consider the same example as we described in section 5.9.2:

- MNO A’s true estimate of its site building cost is €80K.
- If MNO A bids €80K, and wins the auction, it will make no profit – the revenues from other MNOs will cover the cost, but that’s all.
- Moreover, if MNO A bids €80K, and then finds out that all the other MNOs bid €100K or more, it will regret bidding so low – it could have bid higher (up to €99K), still won the auction, and received higher payments.
- But if MNO A bids €90K, hoping to make a profit, and then finds that MNO B has bid €88K, it will wish it had bid lower.

For a single auction, this dilemma can be avoided by adopting a second price rule: the lowest bidder wins, but the winning price is equal to (or only slightly lower than) the second lowest bid. A broadly equivalent approach to a second price sealed bid auction would be a descending price multiple round auction, with the final price of the site set at the level where there is only one remaining bidder. With either of these auction formats, every bidder is incentivised to bid its true estimated building cost, with no fear of regret.

The analysis becomes a bit more complicated when we take account of the fact that there will be lots of auctions for lots of cell sites. If a second price rule is adopted, and all bids are visible to all participants, then MNOs will start observing patterns in each other’s behaviour. For instance, if MNO A consistently bids much lower than MNO B, then MNO B may feel that it should start bidding lower than its true estimated build cost; it doesn’t expect (and doesn’t want) to win the auction at this price, but can reduce MNO A’s winning price and thus reduce its own payments. We suggest three possible approaches for collaborating MNOs to consider:

1. Adopt a second price rule as described above, but in a way that does not reveal the winning (i.e. lowest) bid. All that is revealed is (a) the identity of the winning bidder and (b) the winning *price*, which is equal to the *second* lowest bid. This can be achieved by using a descending multiple round auction, or by placing bids via a trusted auctioneer (or, alternatively, by the use of secure multi-party computation [10] – but this is probably overkill).
2. Adopt a simple, first price rule, as currently used in Hong Kong. The challenges identified above apply, but bidders will learn over time what bidding strategies work in practice.

3. Establish a collective scheme fund, to which individual MNOs contribute a known fee, set in advance over a period of several years. The scheme fund is then used to pay the winning bidders for as many sites as prove affordable in each year (with winning bidders and winning prices established via a second price or descending multiple round auction). The level of annual fee contributed by an MNO could buy a certain amount of “eligibility” to participate in a number of individual site auctions, and then share the resulting sites; the price that each sharing operator pays to share a site is not directly affected by the winning price for that site (and so bidders would not have an incentive to artificially reduce their bids for individual sites). This eligibility mechanism would allow MNO differentiation, and encourage MNOs to join in only sites that they really value (rather than joining in at all sites regardless of business value).

5.9.4 Concluding remarks and clarification

In Hong Kong, the “electronics” (radio head, control unit) are shared, as in our Alternative 2. But the same economic and business arrangement could in principle also be used with Alternative 1, and we use the term “Hong Kong model” there too.

What exactly is included in the “shared cell” may vary from one alternative to another (e.g. each tenant operator may have to install some equipment of their own, or make some backhaul arrangements of their own). In that case, the “Hong Kong model” for decision making and business and economic aspects might need to be tuned to the circumstances.

More detail about the site sharing arrangements in Hong Kong can be found in Appendix 1.

6 EVALUATION OF ALTERNATIVES

6.1 Evaluation of alternatives against criteria

We present the assessment of the alternatives from Section 5, against the evaluation criteria from Section 4, in the form of a matrix below.

			Assessment criterion								
			1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
Alternative	1: Share the physical site and mast, but with own electronics and own licensed spectrum	1.a One (host) MNO acquires access to the site, and other (tenant) MNOs lease access from the host	Medium	No change compared to standard deployment	Medium - MNOs can build where their networks need it, or where they think other MNOs will want to lease. But it may sometimes be better value to wait, in the hope that another MNO will build and be host. This may depend on what the financial arrangement is between host and tenant.	Depends on the charges that tenants pay. If they're low, then MNOs will generally all have the same sites, and it's much the same as for 1.c. If they're higher, more selective choices will be made and more differentiation is likely.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the host MNO's own access contract might depend on how many tenants there are.	None needed, unless having the two antennas so close together needs special filtering, or some new backhaul sharing technology is used.	Regulators may want to inspect the host-tenant agreements, e.g. requiring host to offer open access to all tenants, or limiting the "rent" they can charge	Tenants have no control over siting
Alternative	1: Share the physical site and mast, but with own electronics and own licensed spectrum	1.b MNOs collaborate to acquire and build sites	Medium	No change compared to standard deployment	Good	Poor. Same cell sites for all operators. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Decision making on site acquisition may be difficult	None needed, unless having the two antennas so close together needs special filtering, or some new backhaul sharing technology is used.	No problem anticipated - sharing arrangements are quite common, and this is a minimal kind of sharing	Some compromise required, but all MNOs can influence

			Assessment criterion								
			1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
		1.c Towers company acquires access to site and builds mast; MNOs lease access	Medium	No change compared to standard deployment	Quite good - may be some caution, unless MNOs give strong enough promises that they will use the new site	Rather poor. In terms of cell siting, you can only differentiate by choosing NOT to use a site. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the Towers company's own access contract might depend on how many tenants there are.	None needed, unless having the two antennas so close together needs special filtering, or some new backhaul sharing technology is used.	No problem anticipated	Tenants have no direct control over siting
		1.d "Hong Kong Model": Operators agree sites collectively, then host operator determined by auction (lowest bidder wins)	Medium	No change compared to standard deployment	Good - any MNO can trigger a new site acquisition (shared if at least one other MNO wants to share, otherwise sole)	Rather poor. In terms of cell siting, you can only differentiate by choosing NOT to use a site. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the host operator's own access contract might depend on how many tenants there are.	None needed, unless having the two antennas so close together needs special filtering, or some new backhaul sharing technology is used.	No problem anticipated	Some compromise required, but all MNOs can influence

			Assessment criterion								
			1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
	2: Share site and electronics, but using own licensed spectrum	2.a One (host) MNO acquires access to the site, and other (tenant) MNOs lease access from the host	Medium-Good. Some extra equipment cost but good savings from sharing.	No change compared to standard deployment	Medium - MNOs can build where their networks need it, or where they think other MNOs will want to lease. But it may sometimes be better value to wait, in the hope that another MNO will build and be host. This may depend on what the financial arrangement is between host and tenant.	Depends on the charges that tenants pay. If they're low, then MNOs will generally all have the same sites, and it's much the same as for 1.c. If they're higher, more selective choices will be made and more differentiation is likely.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the host MNO's own access contract might depend on how many tenants there are.	Not needed - MORAN is established technology	Regulators may want to inspect the host-tenant agreements, e.g. requiring host to offer open access to all tenants, or limiting the "rent" they can charge	Tenants have no control over siting
		2.b MNOs collaborate to acquire and build sites	Medium-Good. Some extra equipment cost but good savings from sharing.	No change compared to standard deployment	Good	Poor. Same cell sites for all operators. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Decision making on site acquisition and antenna orientation may be difficult. Security will be harder than without this sharing.	Not needed - MORAN is established technology	None anticipated	Some compromise required, but all MNOs can influence

			Assessment criterion								
			1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
		2.c Towers company acquires access to the site and erects mast and electronics; MNOs lease access	Medium-Good. Some extra equipment cost but good savings from sharing.	No change compared to standard deployment	Quite good - may be some caution, unless MNOs give strong enough promises that they will use the new site	Rather poor. In terms of cell siting, you can only differentiate by choosing NOT to use a site. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the Towers company's own access contract might depend on how many tenants there are.	Not needed - MORAN is established technology	None anticipated	Tenants have no direct control over siting
		2.d "Hong Kong Model": Operators agree sites collectively, then host operator determined by auction (lowest bidder wins)	Medium-Good. Some extra equipment cost but good savings from sharing.	No change compared to standard deployment	Good - any MNO can trigger a new site acquisition (shared if at least one other MNO wants to share, otherwise sole)	Rather poor. In terms of cell siting, you can only differentiate by choosing NOT to use a site. Differentiation in terms of spectrum bandwidth is still possible, but may not be very significant in mmWave bands.	Some flexibility: 3G/4G/5G, with or without NB-IoT; slicing	Reasonably straightforward, except that the host operator's own access contract might depend on how many tenants there are.	Not needed - MORAN is established technology	None anticipated	Some compromise required, but all MNOs can influence

			Assessment criterion								
			1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
3: National roaming between operators. (Cell owner's PLMN ID is naturally displayed on screen.)			Good, as long as each MNO builds a similar number of sites (so roaming charges roughly cancel out)	Worse than with standard deployment - multiple MNOs sharing one MNO's spectrum	Bad - it's better value to roam onto a site someone else builds than to build the site yourself	Bad - same service from all MNOs. (Arguably a slight visual advantage to the cell owner whose PLMN ID is displayed.)	None	Could be challenging. If same PLMN ID in "sharing bands" and "non-sharing bands" then there will be a lot of roaming attempts rejected. If separate PLMN ID for "sharing band" then handover when moving in or out of small cell coverage may be problematic.	None	Likely to be required in many countries, and may require changes to existing regulation, not just special terms in the licensing conditions for a new band	Flexible: no limitation on MNOs building where they want, but the more you take advantage of roaming, the less you influence site choices
4: “Towers” company builds sites and “owns” spectrum, operators roam on. (Towers company PLMN ID is naturally displayed on screen.)	4.1 Automatic access to all sites for all licensed operators	4.1.a Towers company makes its own choices, builds where it thinks it can attract MNOs	Potentially good	No change (on average) compared to standard deployment. (We assume that the spectrum available to the towers company is the aggregate of what the individual MNOs would have licensed individually.)	Slightly bad - towers company may be cautious about building sites without guaranteed usage. (May depend on how exactly the towers company is paid.)	Bad - same service from all MNOs	None	Straightforward	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Tenants have no direct control over siting

				Assessment criterion								
				1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
			4.1.b MNOs are shareholders in towers company, and influence new site decisions that way	Potentially good	No change (on average) compared to standard deployment	Incentive to build where MNOs want - but lack of resulting differentiation means that MNOs may not push hard	Quite bad - same service from all MNOs, but at least MNOs can try to improve their own networks where they think it's most needed	None	Technically straightforward; decision making may not be simple	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band. Operator influence on site decisions may also be of interest to regulators.	Some opportunity to influence site choices, but may not be entirely straightforward
			4.1.c MNOs pay to prioritise their preferred locations (or an interested third party, e.g. a stadium owner, could pay to prioritise a location)	Potentially good	No change (on average) compared to standard deployment	Incentive to build where MNOs want - but lack of resulting differentiation means that MNOs may not push hard	Quite bad - same service from all MNOs, but at least MNOs can improve their own networks where they think it's most needed	None	Technically straightforward; decision making potentially fairly simple too	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band. Operator influence on site decisions may also be of interest to regulators.	Direct opportunity to influence site choices

				Assessment criterion								
				1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
		4.2. Operators pay for access to individual sites	4.2.a Towers company makes its own choices, builds where it thinks it can attract MNOs	Potentially good	No change (on average) compared to standard deployment	Towers company can ask MNOs in advance "if I build here, will you use it?". But may still be cautious about the costs of exploring new site options.	Quite bad - although MNOs can choose which sites they pay to access, the towers company will generally build on sites of equal interest to all MNOs	None	If an MNO pays to access some of these sites and not others, there will be a lot of roaming attempts rejected; however, this problem goes away if this alternative is combined with alternative 6.	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Tenants have no direct control over site choices, but can choose to pay for access to the sites they find most useful
			4.2.b MNOs are shareholders in towers company, and influence new site decisions that way	Potentially good	No change (on average) compared to standard deployment	Fairly good - some incentives to build where individual MNOs want and will pay	Medium	None	Site decision making may not be simple. If an MNO pays to access some of these sites and not others, there will be a lot of roaming attempts rejected; however, this problem goes away if this alternative is combined with alternative 6.	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band. Operator influence on site decisions may also be of interest to regulators.	Some opportunity to influence site choices, but may not be entirely straightforward; can also choose to pay for access only to sites that are sufficiently useful to them

		1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
		Assessment criterion								
	4.2.c MNOs pay to prioritise their preferred locations (or an interested third party, e.g. a stadium owner, could pay to prioritise a location)	Potentially good	No change (on average) compared to standard deployment	Potentially good (operators pay for choice of site and access to site)	OK - MNOs influence decisions about both building and use of sites	None	Site decision making potentially fairly straightforward. If an MNO pays to access some of these sites and not others, there will be a lot of roaming attempts rejected; however, this problem goes away if this alternative is combined with alternative 6.	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band. Operator influence on site decisions may also be of interest to regulators.	Direct opportunity to influence site choices – and needn't pay for access to sites that you haven't influenced to your satisfaction
5: Share spectrum	5.1 I have my own cells, but can use your spectrum as well as my own, as long as I don't interfere with your cells. (Spectrum owner has priority.)	Quite bad - no per site saving. Some MHz gains, so higher speed or capacity or cell size; but some extra caution (testing) required when locating.	Better than with standard deployment	Fairly good (similar to when there's no sharing, but a little extra caution needed)	Good	Good	Could be some problems and cost	Possibly needed to detect / avoid interference - input needed	Likely to be required in many countries - but could be part of the licensing conditions for a new band	No limitation on site selection
	5.2 Pool spectrum at a single site	Quite bad - no per site saving. Slightly increased coverage if demand is not too high.	No change (on average) compared to standard deployment	Used in conjunction with another alternative; pooling spectrum does not itself affect site incentives	Bad - same service from all MNOs - unless vendors implement means to partition resources unequally	None	Reasonably straightforward, except that the host MNO's own access contract might depend on how many tenants there are.	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Used in conjunction with another alternative; pooling spectrum does not itself affect site selection

				Assessment criterion								
				1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
			5.3 Voluntarily pool spectrum as part of wider small cell agreement	May help reduce number of mast-heads needed per site; also reduce costs of interference	No change (on average) compared to standard deployment	Used in conjunction with another alternative; pooling spectrum does not itself affect site incentives	Used in conjunction with another alternative; whatever differentiation that provides	Used in conjunction with another alternative; whatever differentiation that provides	Reasonably straightforward in most cases, but depends on wider site share agreement. Could be more difficult to operate in case of sub-alternative ii)	None	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Used in conjunction with another alternative, could reduce the total number of sites needed
			5.4 Band partitioned into exclusive use and sharing pools	May help reduce number of mast-heads needed per site; also reduce costs of interference	No change (on average) compared to standard deployment	Good; whatever is provided through sharing agreement plus sites to use exclusive spectrum	Good; whatever is provided through sharing agreement plus sites to use exclusive spectrum	Good; whatever is provided through sharing agreement, plus opportunity for additional differentiation at any exclusive use sites.	Reasonably straightforward in most cases, but depends on wider site share agreement.	None	Would be required to define the pools and sharing conditions; part of the licensing conditions for a new band	Used in conjunction with another alternative, could reduce the total number of sites needed
	6: Broadcast multiple PLMN IDs, for same spectrum	6.1 Participants' spectrum all used at shared sites	6.1.a Cross-MNO agreement mechanism for selection and building of sites	Potentially good, unless MOCN technology is expensive	No change (on average) compared to standard deployment	Good	Bad - same service from all MNOs - unless vendors implement means to partition resources unequally	None	Decision making on site acquisition and antenna orientation may be difficult. Security will be harder than without this sharing.	MOCN is established technology. Means to partition resources unequally, to create competition and allay regulatory concern, exist but may not have been implemented by all vendors.	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Some compromise required, but all MNOs can influence

				Assessment criterion								
				1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
			6.1.b Spectrum allocated to TowerCo, which builds cells	Potentially good, unless MOCN technology is expensive	No change (on average) compared to standard deployment	The same as for any variant of alternative 4	Bad - same service from all MNOs - unless vendors implement means to partition resources unequally. Some site choice approaches (as for variants of alternative 4) allow individual MNO influence.	None	Technically straightforward. Site decisions vary similarly to the variants of alternative 4 (so potentially also fairly straightforward).	MOCN is established technology. Means to partition resources unequally, to create competition and allay regulatory concern, exist but may not have been implemented by all vendors.	Likely to be required in many countries - but could be part of the licensing conditions for a new band. For some site selection approaches, operator influence may also be of interest to regulators.	Similar to variants of alternative 4, some of which allow MNOs to influence site building to meet their needs
		6.2 Some spectrum used for shared sites, some kept for sole MNO use	6.2.a Cross-MNO agreement mechanism for selection and building of sites	Potentially good, unless MOCN technology is expensive (and assuming that plenty of cells are shared)	No significant change (on average) compared to standard deployment, as long as partitioning is well judged	Good	Shared sites offer same service for all MNOs, but any MNO that wants to differentiate in a location can do so	No service differentiation on shared sites (but an MNO that wants to offer differentiated services has a way to do so)	Decision making on site acquisition and antenna orientation may be difficult. Security will be harder than without this sharing. Partitioning spectrum between shared and sole use will need care.	MOCN is established technology. If differentiation is ONLY through unshared sites, then no new technology is needed; otherwise as for 6.1.a.	Likely to be required in many countries - but could be part of the licensing conditions for a new band	Some compromise required, but all MNOs can influence - and any MNO can build an unshared site where it has particular demand

	Assessment criterion								
	1: Cost per MNO per site that their customers can use	2. MHz per customer served	3: Incentives to build sites	4.a: Ability to differentiate (sites and bandwidth)	4.b: Ability to differentiate (services on a given site)	5: Ease of operation / seamlessness	6: Requirement for new technology	7: Requirement for regulatory change	8: Meeting MNO coverage and capacity needs
6.2.b Some spectrum allocated to TowerCo, which builds shareable cells; other spectrum licensed to individual MNOs for exclusive use	Potentially good, unless MOCN technology is expensive (and assuming that plenty of cells are shared)	No significant change (on average) compared to standard deployment, as long as partitioning is well judged	The same as for any variant of alternative 4	Shared sites offer same service for all MNOs, but any MNO that wants to differentiate in a location can do so	No service differentiation on shared sites (but an MNO that wants to offer differentiated services has a way to do so)	Technically straightforward. Site decisions vary similarly to the variants of alternative 4 (so potentially also fairly straightforward). Partitioning spectrum between shared and sole use will need care.	MOCN is established technology. If differentiation is ONLY through unshared sites, then no new technology is needed; otherwise as for 6.1.b.	Likely to be required in many countries - but could be part of the licensing conditions for a new band. For some site selection approaches, operator influence may also be of interest to regulators.	Similar to variants of alternative 4, some of which allow MNOs to influence site building to meet their needs. Also any MNO can build an unshared site where it has particular demand.
7: Shared secondary node connected to different MNOs' master nodes	Potentially good (as per alternative 6)	No significant change (on average) compared to standard deployment, as per alternative 6	This can be seen as a refinement any of the variants of alternative 6; incentives to build are the same as for those alternatives.	This can be seen as a refinement any of the variants of alternative 6; opportunities to differentiate are better than those alternatives, though, because small cell capacity is used as part of a differentiated overall offering.	Some opportunity to differentiate through supporting different services at the master node	Largely similar to alternative 6. How to avoid interference with unshared secondary nodes depends on the spectrum arrangement.	MOCN is established technology. Having one secondary node supporting master nodes from different MNOs simultaneously is likely to require some standards development (but not major).	Likely to be required in many countries, but sharing of secondary nodes only may be more acceptable since clear differentiation remains. Some spectrum pooling arrangements may also need regulatory permission.	This can be seen as a refinement any of the variants of alternative 6; incentives for site selection are the same as for those alternatives.

6.2 Use of mmWave small cells with a lower frequency anchor layer

mmWave cells on their own are not very effective for most use cases. Instead, they should normally be used alongside a lower frequency anchor layer (5G or LTE), that provides mobility management and reliable signalling. Standalone mmWave cells are technically possible in principle, but won't work well in practice for most use cases.

This raised concerns about some of the alternatives identified in Section 5, e.g.:

- We considered national roaming just in the mmWave band (Alternative 3). But will this really work? If a Vodafone customer can roam onto T-Mobile's mmWave small cell, but not onto T-Mobile's lower frequency cells, then where is the anchor layer?
- We considered "towers company" approaches. If the towers company just builds and operates the sites, but each operator uses their own spectrum in a standard MORAN sharing arrangement (one variant of Alternative 2), then each operator has its own anchor layer too – no problem. But if the towers company itself owns the spectrum, and operators roam on (Alternative 4), then again there's no natural anchor layer.

However, it seems technically feasible for a customer to be connected simultaneously to one operator's lower frequency anchor cell (as "master" eNodeB or gNodeB) and another operator's mmWave small cell (as "secondary" gNodeB). This requires an X2 or Xn interface to exist between the master and secondary node, so it is only possible where the two operators have agreed to enable it.

At the time of writing, we are in the process of asking 3GPP for their advice on whether this architecture is already fully supported by the standards, or whether some (minor) changes would be needed to support it. The conclusion of this section, though, is that Alternatives 3 and 4 are not precluded by the need for an anchor layer.

7 CONCLUSIONS

Based on the evaluation presented in the matrix above, we recommend two approaches that appear to provide the greatest benefits. However, we do not believe that a regulator should impose a particular cost reduction or sharing arrangement against the best advice of the operators, which could make the telecoms services marketplace less competitive.

7.1 Recommended approach #1

The first alternative that we recommend operators to consider is Alternative 2 (i.e. MORAN sharing): share the physical site, and share as much as possible of the "electronics" (antenna and baseband unit), but with each operator using their own licensed spectrum. From a regulatory point of view, this should not be especially challenging – there are already plenty of cases of sharing along these lines.

Regarding the responsibilities, decision making, and financial arrangements, we recommend that operators consider adopting the "Hong Kong model" outlined in section 5.9. (We noted in section 5.9.3 that alternative auction formats could be considered for use with the Hong Kong model.)

Backhaul from the shared small cell would typically be a shared connection to an existing, high quality, national or regional fibre network, on which all operators concerned have breakout points to their individual core networks. The connection from the small cell to the fibre network may be fibre all the way, or may include a wireless leg; the considerations for this decision are not significantly different from those affecting an unshared cell, except that the total capacity requirement may be greater.

7.2 Recommended approach #2

The second approach that we recommend operators to consider is based on MOCN sharing, but specifically tailored to the small cell use case. It aims to achieve the greater cost savings of MOCN sharing, while addressing regulator concerns about the reduction in competition that MOCN sharing may bring.

The key element of this approach is to embrace MOCN sharing, but only for high frequency (particularly mmWave) small cells. We recognise that these small cells will primarily be used in a dual connectivity architecture, as secondary nodes in combination with a low frequency (anchor layer) master node. We therefore recommend **secondary node sharing**: a single small cell, shared between multiple MNOs, working as a secondary node in conjunction with the master nodes of multiple MNOs simultaneously.

This concept is illustrated in Figure 7, Figure 8 and Figure 9. These figures all show a common fibre ring being used for backhaul and inter-node signalling, but of course other bearers may be used. Also, all of these figures show only two operators sharing, but the concept can clearly extend to three or more. Each operator, independently, could be using an Option 2 architecture with dual connectivity, or an Option 3 architecture, or an Option 7 architecture; Figure 7, Figure 8 and Figure 9 show some of the possible combinations, but clearly there are others.

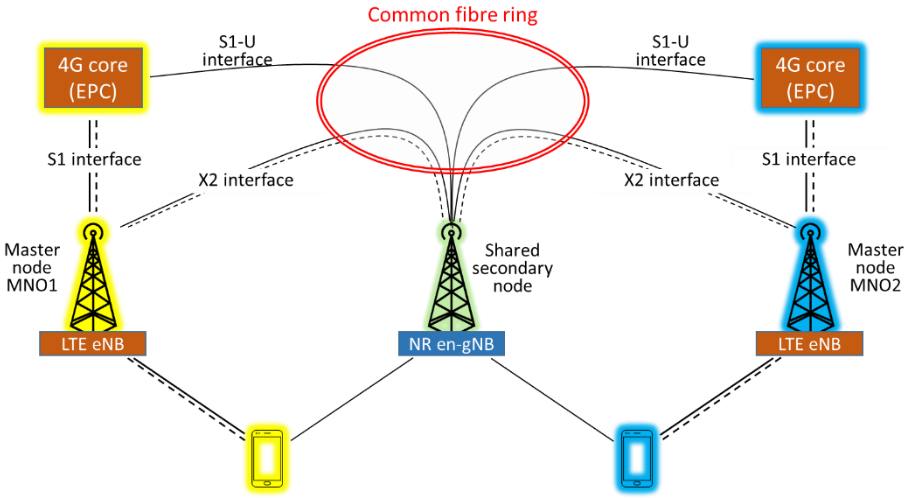

Figure 7: Secondary node sharing (Option 3 for both MNOs)

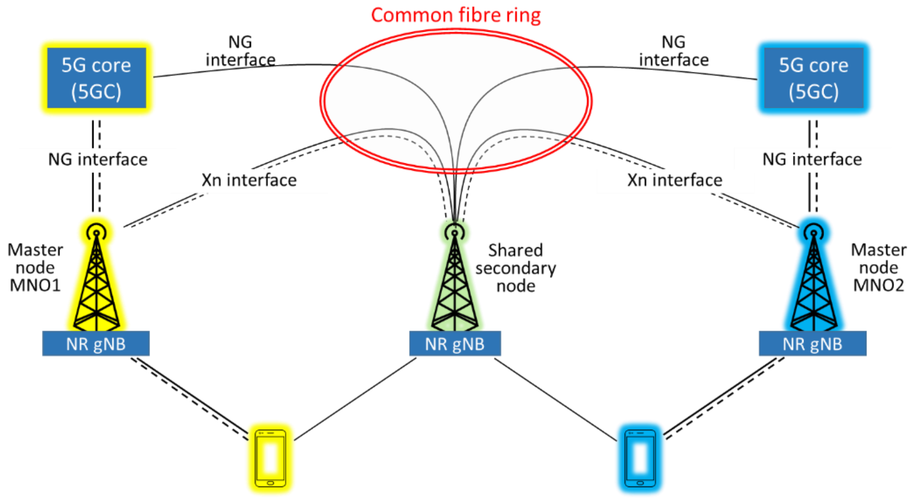

Figure 8: Secondary node sharing (Option 2 with dual connectivity for both MNOs)

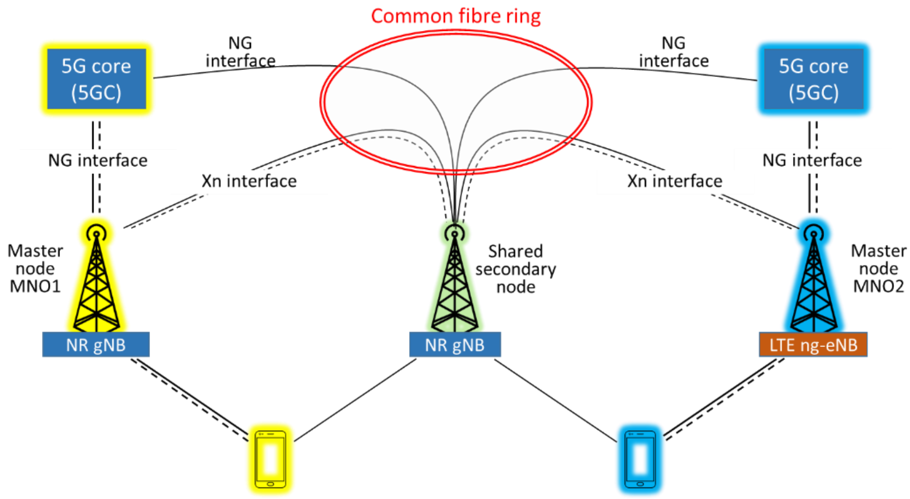

Figure 9: Secondary node sharing (Option 2 with dual connectivity for one MNO, option 7 for another)

Secondary node sharing goes a long way towards addressing the small cell business case challenge that motivates this whole report. It will enable more high capacity small cells to be built, alleviating congestion and improving customer experience. It still allows MNOs to compete on coverage and mobility (and depending on how much spectrum is shared, could also allow MNOs to compete on capacity in particular areas, as explained later in this section).

In terms of how sites are selected, who builds the sites and who brings the spectrum, our recommendation is flexible:

- If individual participating MNOs have licensed spectrum, then the considerations are the same as for regular MOCN sharing (see e.g. [8], section 3.3). We encourage operators to consider adopting the Hong Kong model as a flexible and efficient way to decide who builds which site and how costs are allocated.
- An alternative is for spectrum to be allocated to a neutral host (TowerCo) that builds the sites. This is a more radical approach, and may not be palatable to some operators or regulators. But in a country where the small cell business case looks particularly challenging, it may be the best way to ensure that investment goes towards the small cells themselves rather than, say, to spectrum licence fees. It may therefore be in the best interests of customers.

- If sites are built by a neutral host, it is still up to individual MNOs to decide which of these sites they want to use. Connecting the MNO's network (its master nodes) to the neutral host's small cell (as secondary node) requires some integration. The MNO may be required to pay a fee to access each small cell site.
- If sites are built by a neutral host, the question arises of how sites are selected and prioritised. Based on our evaluation of the variants of Alternative 4, we recommend an approach whereby an individual party (an MNO, or a third party such as a stadium or shopping centre owner) can pay to prioritise particular sites.

It could be that all of the spectrum used in this band to serve participating operators is shared; or it could be that some is shared, while other spectrum is retained by operators for their sole use. We are open to either possibility. In mmWave bands, where very large amounts of spectrum are available, having some spectrum retained for sole use has little disadvantage, and allows some benefits:

- Any MNO whose specific needs are not met by the shared cells can build its own unshared cell with no difficulty and no risk of interference. In particular, an MNO wanting to provide service to an enterprise customer's factory or workplace could do this (whereas other MNOs, who do not have this company as a customer, may have no interest in sharing a cell there).
- This creates greater potential for differentiation between MNOs, which may further help to allay regulator concerns about MOCN sharing.

Our understanding is that, at the time of writing, the secondary node sharing architectures shown in Figure 7, Figure 8 and Figure 9 (and the other combinations of operators using Options 2, 3 and 7) are not yet formally recognised by 3GPP. We are in the process of:

- asking the relevant 3GPP standards groups whether any standards changes are needed to support secondary node sharing;
- requesting that 3GPP recognise secondary node sharing as a valid and worthwhile architecture option in their future work.

This includes the management of interference between gNBs (some shared, maybe also some not shared) using the same frequencies, which we would expect to use (Enhanced) Inter-Cell Interference Coordination techniques [11].

8 APPENDIX 1 – HONG KONG: EVOLUTION TO MOBILE DIGITAL COVERAGE WITH MULTI-OPERATOR SYNERGY

8.1 Introduction

This appendix describes the approach of cell site sharing among different mobile operators in Hong Kong. It also discusses the evolution of indoor coverage design, and the advantages of using digital signal oriented small cell solution over the traditional distributed antenna system.

Considering the sharing of telecom facilities, a use case of multi-operator supported small cell solution will be presented. Several other cases related to MOCN/MORAN deployments in Hong Kong will also be discussed to as practical examples and references to readers

8.1.1 Hong Kong Mobile Market Overview

As one of the most densely populated city in the world, Hong Kong has a large number of high-rise buildings, which includes not only offices but also shopping malls, residential properties, etc. This implies a comprehensive mobile coverage and sufficient capacity at these indoor locations are crucial to provide a satisfactory level of customer experience.

According to one of the Hong Kong mobile operators, 28% of the cell sites are built for indoor coverage, while this 28% of site are taking up 81% of the total traffic in the whole network.

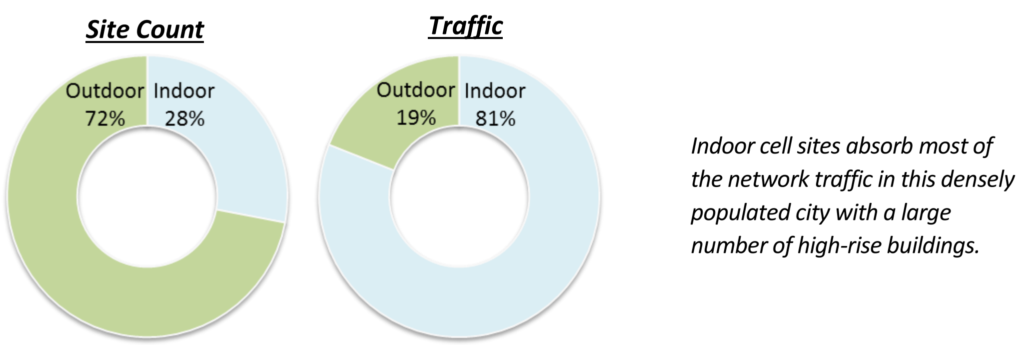

Figure 10: The ratio of the indoor and outdoor cell site and corresponding traffic volume

8.2 Evolution to Indoor Digital Coverage for Multi-Operator Sharing

To address the demanding needs of quality mobile services in the indoor environments, the operators tend to work together in a site sharing manner.

8.2.1 Distributed Antenna System (DAS)

A Distributed Antenna System (DAS) is implemented as a common facility, in which passive antennas will be installed over different floors and locations within the building. A Point-of-Interface (POI) in installed as the interface for different operators to provide the RF inputs to this Integrated Radio System (IRS).
This approach has been adopted over the past 20+ years in Hong Kong. However, there exist some limitations using DAS:

Capacity limitation
From a single POI output, all antennas belong to the same sector serving the whole premise. Capacity and speed is relatively low.

Installation Challenges
Coaxial cables which are used to connect the antennas are thick and heavy which have imposed some challenges to installation and space requirements.

Technically limited Cabling System
The supported RF spectrum is limited with coaxial cables. 5G using higher frequency may not be feasible using the traditional DAS.

8.2.2 Small Cell (LampSite 2.0 / 3.0)

With the emerging uses of small cell, there is a new design for indoor coverage using distributed active radio heads, namely LampSites, to provide the indoor coverage. One major difference is that the system adopted fibre/ethernet, instead of coaxial cables for its cabling system. (In the previous years, such system, namely LampSite 2.0, can support single operator only.)

Capacity Enhancement
Instead of limiting the antennas to one sector under a POI output, different LampSites can be logically group into different sectors. There will be more sectors serving the premise with this design. Capacity and speed are improved compared with DAS.

Installation Flexibility
Compared with coaxial cable, optical fiber or ethernet cables is much lighter and easier to install. Cell site roll out can be more rapid.

Technically limited Cabling System
Optical fiber transmitting digital signals would be future proof for high speed 5G era. Only the radio head, LampSites, are to be upgraded or replaced if required by the new technology is deployed

LampSite 3.0 is the further evolution of the design where multi-operators are supported. Mobile Network Operators (MNOs) can join the system using analog or digital inputs. With analog input, remote radio unit (RRU) is still required, while for digital input, only base band units (BBU) are required by individual MNO to connect to the system through CPRI interface. (Figure 4 illustrates the hardware connection)

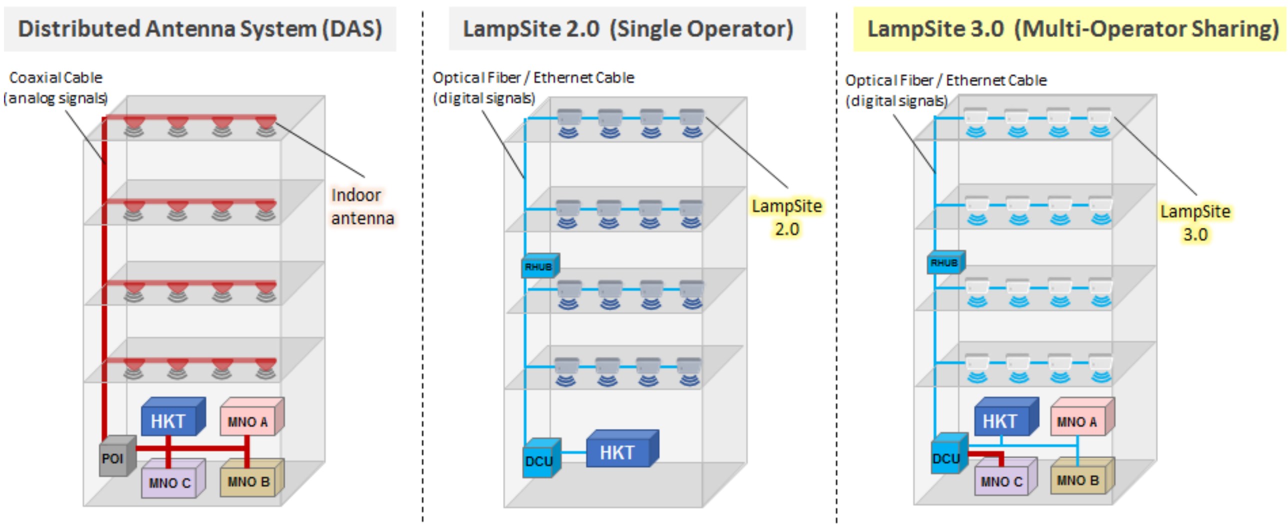

Figure 11: Evolution of Indoor Coverage Design with Multiple-operator Sharing

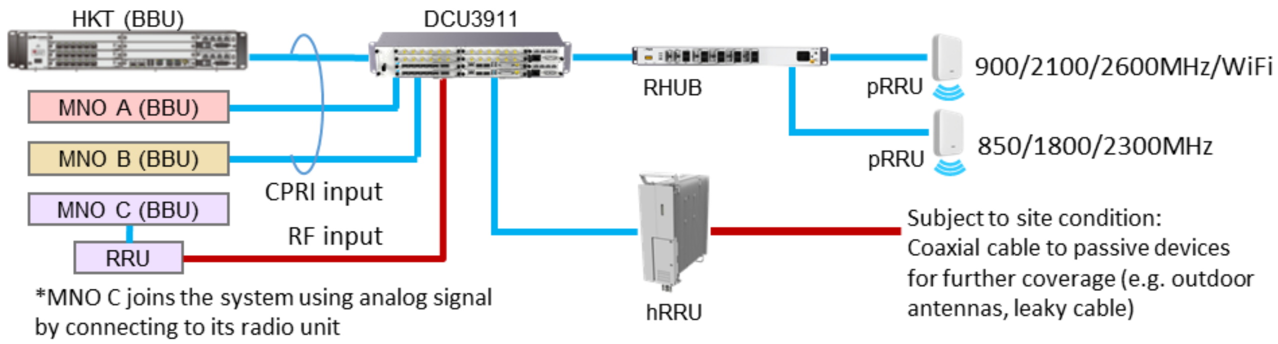

Figure 12: Illustration of the Hardware Connection of the LampSite 3.0

8.2.3 Technologies supported by LampSites

Several advanced mobile technology are supported by the LampSites:

- Carrier aggregation: Combine multiple carriers of frequency bands for larger bandwidth
- High modulation: 256QAM modulation is supported for higher bit rate and data speed
- Mutiple-Input-Mutiple-Output (MIMO): 2x2 MIMO supported by each LampSite. 4x4MIMO can be configured using two LampSite simultaneously for data session)

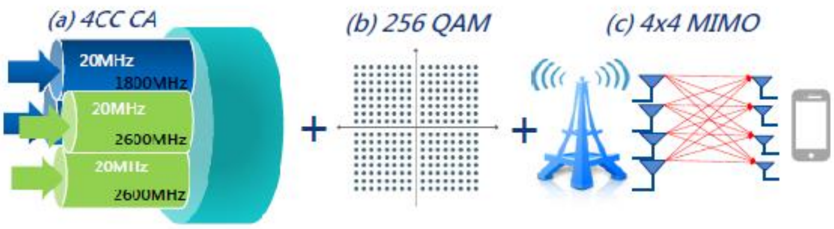

Figure 13: Mobile Technologies – enablers of 1Gbps Mobile Network

To summarize, the benefits of LampSite 3.0 include the followings.

- All fiber architecture are 5G-enabled infrastructure without the need to re-work cabling for 5G
- All frequencies bands (low, mid and high bands) ranging from 850MHz to upcoming 28GHz band for 5G are supported
- Peak throughput achieved by 4x4 MIMO as compared with a 2x2 MIMO only through dual coaxial cables of DAS solution
- Extremely high capacity of supporting full frequencies bands by pRRU at each radiating point as compared with DAS solution by RRU over a group of radiating points at multiple indoor antennas
- Hybrid solution of both LampSite 3.0 and DAS supported enables the business cases to be flexible for each operator to decide individually to share the cost of LampSite 3.0 or DAS.

8.3 LampSite 3.0 Deployment - Case Reference: Shatin to Central Link

Shatin to Central Link (SCL) is an under-construction expansion of the MTR rapid transit network in Hong Kong. The cost of Hong Kong's new rail link from Shatin to Central is expected to be around HK$87.32 billion (US$11.17 billion), making it the most expensive rail project in the city's history.

Figure 14: Overview of Shatin to Central Link, a new metro line in Hong Kong

HKT is nominated to be the Lead-Operator of this project for the construction of mobile network system. LampSite 3.0 is being deployed, as the world's 1st project to support multi-operator sharing in a digital mobile system for metro line coverage. Some of the challenges include the followings:

<u>Multiple Operators</u>
The system has to be technology-neutral to support multi-operator scenario, e.g. analog/digital inputs.

<u>Multiple Radio Access Technology (RAT)</u>
Several existing RATs have to be supported, e.g. GSM / UMTS / FD-LTE / TD LTE.
Future 5G using higher frequency bands may require hardware upgrade.

<u>Short Installation Time Window available due to Train Operation</u>
MTR stations are currently in operation. Tight restriction on installation time window imposes

By deploying LampSite 3.0, Multiple operators, RATs and flexible inputs by digital/analog signals are all supported. In this project, LampSites (pRRU / picoRRU) are planned at concourse/platform areas to maximize the benefits of the new system. Whereas, from a maintenance point of view, leaky cables are installed in the tunnel tubes, since the access to tunnel tubes is limited with tight maintenance time, only available during the non-operating hours. Passive devices with less requirements on hands-on configuration and less potential needs of maintenance will be preferred in this case. On the other hand, we may see that not only coverage provision by leaky cable is possible, connection to other types of passive antennas are also feasible, as we may have different coverage design to cope with different type of site conditions.

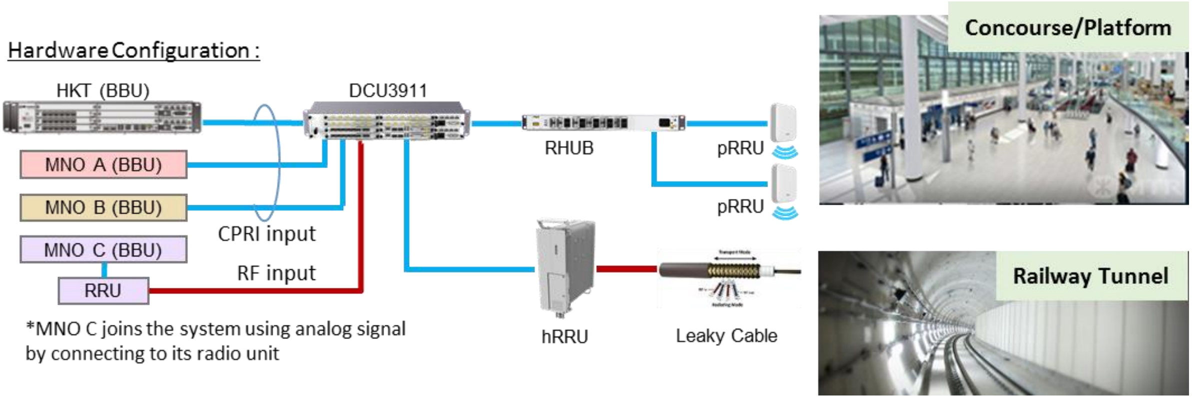

Figure 15: Illustration of LampSite 3.0 Coverage Design in SCL

8.4 Integrated Radio System – Business Model with Competitors in Collaboration

The approach of building an Integrated Radio System (IRS) would be a cost effective way for operators to provide coverage at specific locations where they see the needs of mobile services. The MNO offering the lowest Bid will be winner / host to build the system. By such collaboration, the total cost can be minimized, in favor of the common interest of operators.

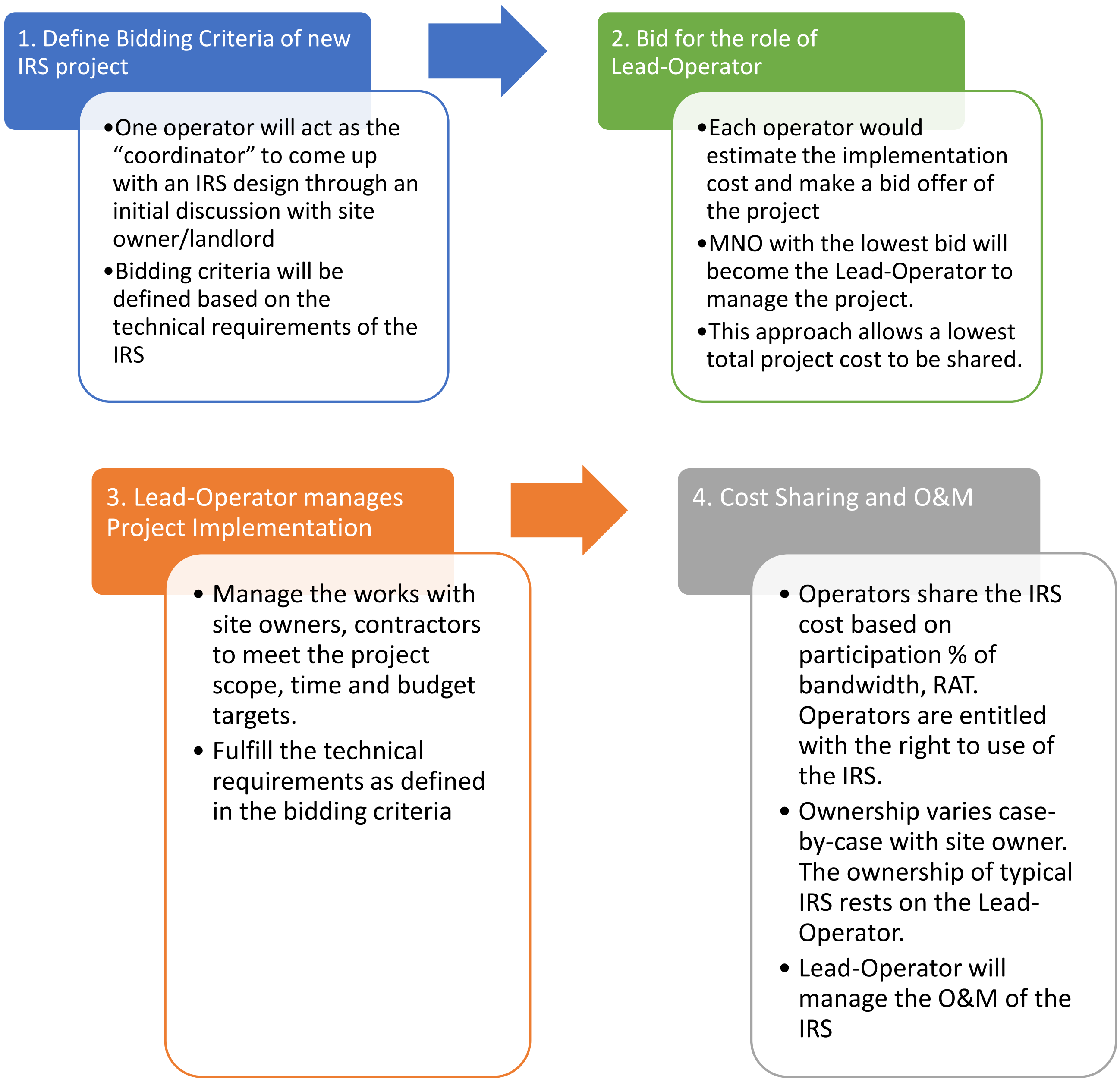

Figure 16: Typical Project Life Cycle of an IRS Project

Various costs will be involved for an IRS site to be shared among operators, for a typical project, three main associated costs are listed as below

<u>Project Cost</u>
The project cost to implement the common facilities based on the technical requirements to be shared among operators.
In DAS, we may refer to the cabling system, antennas installed in the premises and Point Of Interface for all operators. In LampSite 3.0, we may refer to the fiber cabling system, small cells and the associated electronics being shared.
It includes all the associated cost such as costs of equipment, installation, etc.

<u>Rental Cost</u>
The rental or license fee due to the space occupied by the telecom equipment payable to the site owner / landlord by operators.
This would be subject to the negotiation with the landlords for the monthly rental paying to the them. For a common practice in Hong Kong, payable to landlord is usually in fixed amount regardless of how many operators are joining the system.

<u>O&M Cost</u>
The on-going operation and maintenance (O&M) cost of the IRS payable to Lead-Operator by joining operators.
As the Lead-Operator will be responsible for the O&M of the system, it is agreed that monthly O&M fee will be collected among the operators for the regular operation of the IRS, administration works with the landlord and carrying out any repairment if required for the system.

8.5 LampSite 3.0 Cost Sharing by MNOs - Case Reference: Shatin to Central Link

8.5.1 Bidding Process of the First LampSite 3.0 Project

The LampSite 3.0 project at Shatin to Central Link is the first small cell sharing project in Hong Kong. The cost is shared among operators through a bidding process as described in session 4.
Since it was the first deployment of the LampSite 3.0, it was agreed among MNOs that each MNO can choose to join the system by means of digital or RF inputs. Therefore for such bidding process, each MNO will come up with two bid offers: **1) DAS**, and **2) LampSite 3.0**.

MNOs who join the system will share the **basic project cost** of **1) DAS**; and
MNOs who join the system **by digital inputs** will share the **additional cost** for **2) LampSite 3.0**.

In this project, HKT offered the lowest bid of LampSite 3.0 and was awarded as the lead-operator. Thus, the basic project cost will be shared among all MNOs (all 4 MNOs in this case) and the cost differences between LampSite and DAS will be shared by MNOs using digital inputs (2 MNOs in this case).

On average, MNOs expect the cost of LampSite 3.0 would be 24% higher than traditional DAS. Such premium is justified by the benefits as described in session 2.3.

8.5.2 Cost Distribution of LampSite 3.0 Solution

The Total Cost of Ownership (TCO) of LampSite 3.0 is subject to several factors:
scale of the project, cell sites sizes, vendor's offerings, fees required by the landlord/site owner, etc. Thus, the total amount varies according to different project and respective conditions. In this project, the major project costs items are presented as below for references:

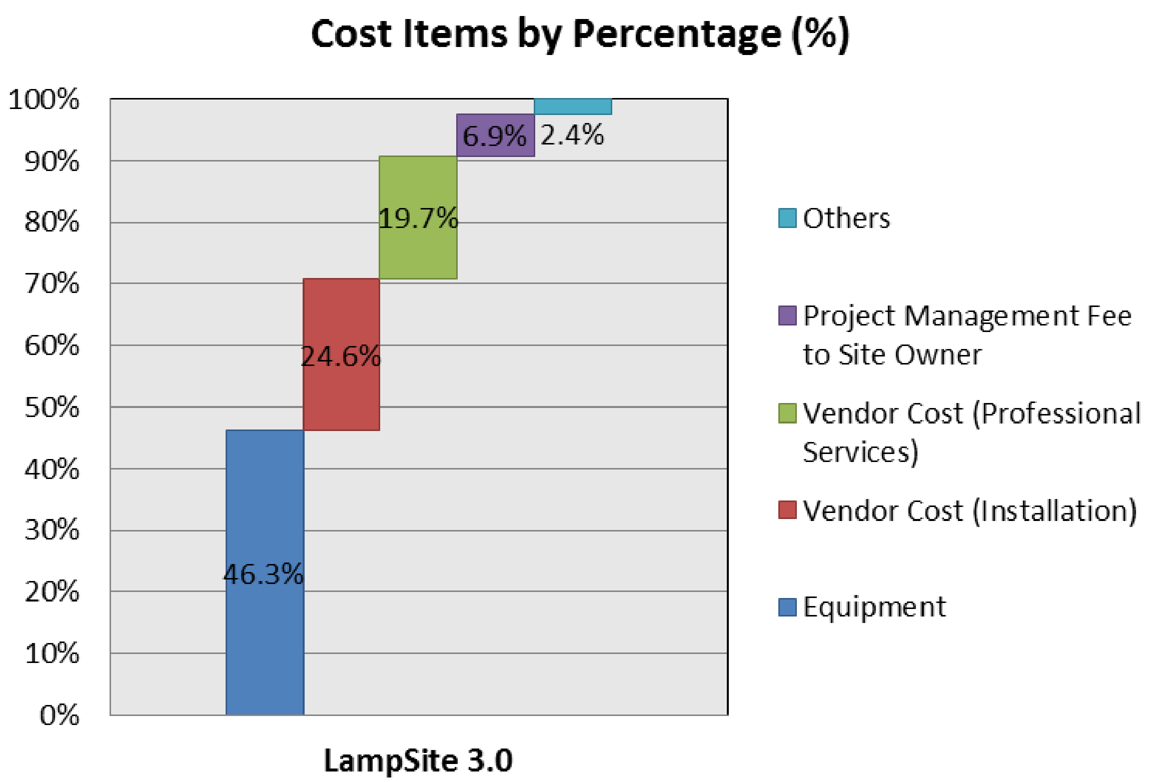

Figure 17: Major Cost items in a LampSite 3.0 Project - SCL

Equipment Cost

This refers to the shared equipment and facilities of the system, including the active electronics such as LampSites, hRRU, DCU, etc, and passive devices such as antennas, leaky cables, etc. This part of the cost is generally larger than the DAS, as per each indoor location, indoor passive antennas are replaced by active small cell units, which are more expensive electronics.

Vendor Cost (Installation)

This refers to the installation services provided by the vendor/contractor. Although the fibre/Ethernet cables would be easier to install than coaxial cables, they may also requires some other new accessories such as conduits for accommodating the fibre cabling. Workers would also have more electrical works since all the radio heads (lamp sites) are more decentralized and distributed, hence the cost of this part will generally be higher than that of DAS also.

Vendor Cost (Professional Services)

This refers to the design and commissioning by the telecom equipment vendor. At the first/early stage of the deployment of this new solution. More supports are expected from the vendor to design and commission the system, where such costs were not necessary in the traditional DAS. Hence, MNOs may expect that the related costs would be included for deploying this new solution in the future before the related knowledge is acquired such that the related works can be handled internally.

Project Management Fee to Site Owner

In this project, due to the complexity of this metro line infrastructure, the site owner requires a project management fee to coordinate all the activities related to the provision and installation of the equipment in their premises. This fee was also agreed among operators to share by the same principle as part of the project cost.

Others

This includes some other expenditure, such as miscellaneous fee on arranging transmission and power facilities, administration works with site owner, internal overhead, etc.