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Small Cell Backhaul Requirements

next generation mobile networks

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by the NGMN Alliance

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Project:	**Backhaul Evolution**
Editor / Submitter:	**Julius Robson, Cambridge Broadband Networks**
Contributors:	**Orange, Alcatel Lucent, Nokia Siemens Networks, NEC, Huawei, Cisco, Everything Everywhere**
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Commercial Address:
ngmn Ltd.,
Friedrich-Ebert-Anlage 58 • 60325 Frankfurt • Germany

Phone +49 69/9 07 49 98-04 • Fax +49 69/9 07 49 98-41

Registered Office:
ngmn Ltd.,
Reading Bridge House • George Street • Reading • Berkshire RG1 8LS • UK
Company registered in England and Wales n. 5932387,
VAT Number: GB 918713901

Executive Summary

Operators are currently considering deployment of small cells as a complement to their macrocell networks to improve coverage at 'not-spots' and ease congestion at 'hot-spots'.

Backhaul is a key challenge, but there is uncertainty around which solutions are most suitable. This NGMN white paper aims to help move the industry forward by clarifying consensus around the operators' requirements for small cell backhaul. The focus is on operator deployed, open access small cells and the 'last mile' of the backhaul. Many of the backhaul requirements for small cells are the same as those for macro sites, however there are some differences:

- Cost per small cell backhaul connection will need to be much lower than for macrocells, but user Quality of *Experience* cannot be sacrificed.
- There is however scope to relax some aspects of the offered Quality of *Service*:
  - Backhaul availability may be relaxed for capacity sites at hot-spots.
  - Capacity provisioning may be relaxed for coverage sites at not-spots.
- Small cells dictate the following new requirements for backhaul:
  - Coverage down to street level sites with sufficient QoS.
  - Security, small form factor, and low installation cost.

An initial consideration of several types of wireless and wired backhaul solutions shows that whilst each one may be strong in one type of requirement, no one solution is good for all requirements. It is therefore anticipated that operators will need to address diverse small cell deployment scenarios with a 'toolbox' of backhaul solutions.

Contents

1 Introduction

Consumer demand for mobile broadband services is continually increasing, requiring operators to provide more and more capacity from their radio access networks. This is achieved with a combination of using more spectrum, improved spectral efficiency from '4G' technologies, and by increasing the density of their networks, the number of cells per unit area. Capacity gains of macrocells from using more spectrum, optimization and improved efficiency are unlikely to be enough to keep up with the traffic demand increase, and so significant cell densification will be needed too. Rooftop space available for more large 'macrocell' sites is running out, and so operators are looking to smaller form factor base stations which can be deployed in a wider range of locations. Reducing the size of the basestation results in lower RF transmit power and thus shorter ranges. As such, low power small cells need to be closer to the users they serve, below rooftop and mounted on street furniture or buildings facades.

Deploying large numbers of small cells near to the consumers helps solve the capacity problem for the radio access network, but creates a new one for backhaul, which must provide connectivity at sufficient capacity and quality of service. Small cell backhaul is at an early stage of development, with a wide range of solutions being proposed and considered. This NGMN paper aims to assist the industry to understand what features and performance operators require from their small cell backhaul, helping to identify the types of solutions that will be more effective. Use cases are developed for the small cells according to the scope and priorities of the NGMN study. With this understanding of how small cells will be deployed, requirements are developed for the backhaul needed to serve them. Finally, an overview of the types of solution that might be in the 'toolbox' is given.

1.1 Scope of this paper

The purpose of this study is to capture industry agreement on a set of requirements for small cell backhaul. The following steps are involved:

- Agree on the scope of use cases for small cells
- Consider for different small cell use cases, what is needed from the backhaul, and define requirements
    - Architectures and network topologies, including security aspects
    - Capacity and Quality of Service
- When applicable, address the Total Cost of Ownership (TCO) related to small cells backhauling
- Both 3G and LTE small cells fall within the scope of this study. As such, LTE releases 8, 9 and 10 will be considered in scope of this paper.

1.2 Definition of small cell for the scope of this paper

It is recognized that a univocal definition of a small cell deployment is hard to agree within the Industry. As an example, according to 3GPP [3] cell types are classified based on the 'minimum coupling loss' between cell site and user device, thus originating four classes of cells. Other available definitions consider the radius of the cell, the number of connected users, the deployment options and so on.

In the context of the P-BEV project small cells are identified as those cells that fulfil the following high-level criteria:

- They provide the coverage of an area smaller than a macro cell (so that one macro cell overlaps several small cells in the same area)
- As macro cells, they are deployed and managed by operators
- They grant an open access to all users (of the same operator)
- Are characterized by a lower equipment and installation cost if compared to macro cells
- Are oriented to the support of data services, although voice services can also be supported

The definition of small cells can be further detailed through the technical parameters listed hereafter. It is beyond the scope of this paper to provide values for these parameters except where referenced further on in this paper where use cases or service profiles are characterized by:

- Capacity (defined in terms of average, peak)
- Services supported (best effort data, real time data, voice)
- Mobility support (support of handover between macro and small cells or among small cells, support of the X2 interface, S1/X2 traffic ratio
- Service requirements in terms of QoS (latency, jitter, packet loss, availability) and time and frequency synchronization requirements
- Deployment requirements
    - Power consumption (related to backhauling)
    - Operational conditions (public access, operator's deployed backhaul)
    - Potential location (indoor/outdoor, a few meters above street level or rooftop).

The next section highlights how those parameters are combined together to form the small cells use cases considered in this paper.

2 Use Cases for Small Cells within Scope of Study

Table 1 summarizes the main use case parameters and priorities agreed at the outset of the study

Table 1 Use case parameters priorities agreed at the outset of the study

Small Cell Use Case Parameter	Importance for NGMN Small Cell Backhaul Study		
	Priority	In scope	Out of Scope
Deployment	Operator deployed		Consumer Enterprise
Deployment Motivation	Capacity	Coverage	
Service offerings	Data, different QoS levels and performance	Voice	
Small cell Location	Outdoor, 3-6m above street level	outdoor rooftop & indoor public spaces	
RAN Technologies	LTE FDD	LTE TDD, HSPA, WiFi	GSM[1]
Combinations at one site	LTE only	HSPA only LTE+HSPA, WiFi	multi operator RAN or site sharing
RAN Bandwidths	10 MHz LTE 20 MHz LTE	5MHz & 10MHz HSPA	Multiple bands per technology. Variation with band
Security	3GPP based	Partially enabled	No logical security

The following two high level use cases have been defined to illustrate how to combine the above parameters in some backhaul scenarios for the small cells:

- **1) Best-effort data offload for 3G macrocells**
  - Low cost dense deployment of HSPA small cells & WiFi to offload traffic from macrocells
  - Offer 'best effort', non real time data services (web browsing, video, downloads etc)
    - high capacity is the most important element
    - latency, jitter, availability are considered as less important
  - Voice services and high mobility users pushed to macro-layer
  - Deployed widely in areas of high demand
- **2) Early move to LTE small cells with full service offering**
  - Minimal macro LTE network deployed to achieve base coverage
  - Further capacity enhanced by LTE-only small cells offering same QoS levels as macro layer.
  - Voice and real time data (video, gaming, cloud) all supported
  - Street level outdoor and public indoor locations

Other examples of use cases may be defined in a next stage of this activity.

[1] We note that GSM might be provided in a not spot small cell. In this case the backhaul would still be packet (IP) rather than circuit (E1), and the impact to dimensioning would be small compared to HSPA or LTE.

3 Requirements for Small Cell Backhaul

3.1 Backhaul Architecture

3.1.1 Overview

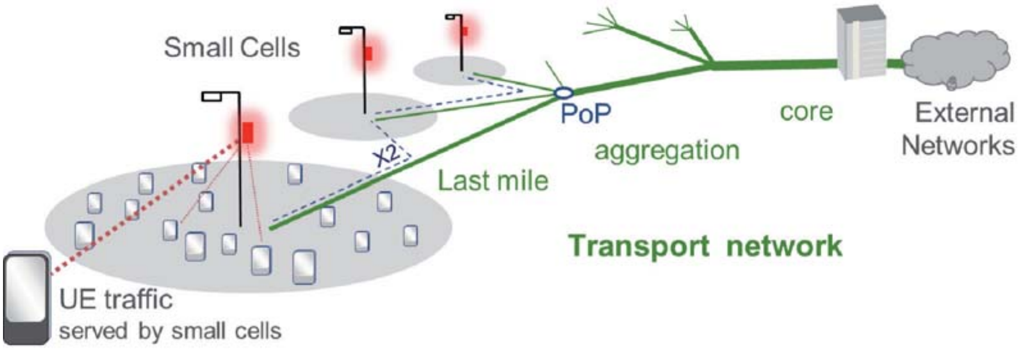

Figure 1: Abstract View of Small Cell Backhaul with Definitions for Key Nodes and Concepts

The *raison d'être* of backhaul is to provide connectivity between the small cells and the core network nodes with desired QoS level. Figure 1 illustrates the nodes and concepts used in this study.

In this document we assume that in majority of the cases there is pre-existing transport infrastructure in place for connecting the existing macro cell base stations to controllers and core nodes. The infrastructure typically consists of a mix of fiber and microwave radio deployments. A further assumption is that operators deploy small cell base stations in addition to the existing macro cell layer of the same radio technology for offering higher capacities in hotspot areas as well as better coverage in certain areas. The combination of small and macro-cell layers is referred to as a "Heterogeneous Network"

For operators not having an existing macro cell layer (also known as Small Cell Greenfield operators) the later described deployment scenarios will be similar. The difference will be however in the usage of fixed networks (based on operator's own or on leased lines) for the hand-off from the dedicated small cell backhaul network to the existing infrastructure.

The new challenge brought by small cells is in providing connectivity from the hard to reach locations below rooftop to a site being part of the existing transport infrastructure.

3.1.2 Small Cell Network Architectures

In the context of this document it is assumed that small cell base stations are similar to macro cell base stations, but purpose and application optimized (size, output power and integration of additional functionality). In that respect a small cell base station uses the same logical interfaces (S1& X2 or Iub or Iuh) as a (e)NodeB, Home (e)NB, as defined in 3GPP TS 36.300 Release 11, and which are also depicted in Figure 2

An optional intermediate aggregation gateway like the HeNB or HNB Gateway may also be used, which offers connectivity to the backhaul network for a number of small cells within a certain area. In the LTE case, the aggregation gateway can act as concentrator for S1 interfaces. Usage of the optional aggregation gateway will be a vendor specific decision, which might include also support of additional functionality compared to the 3GPP definition (see also discussion in chapter 3.1.3).

Selective IP Offloading (SIPTO) can be applied at the local gateway (GW).

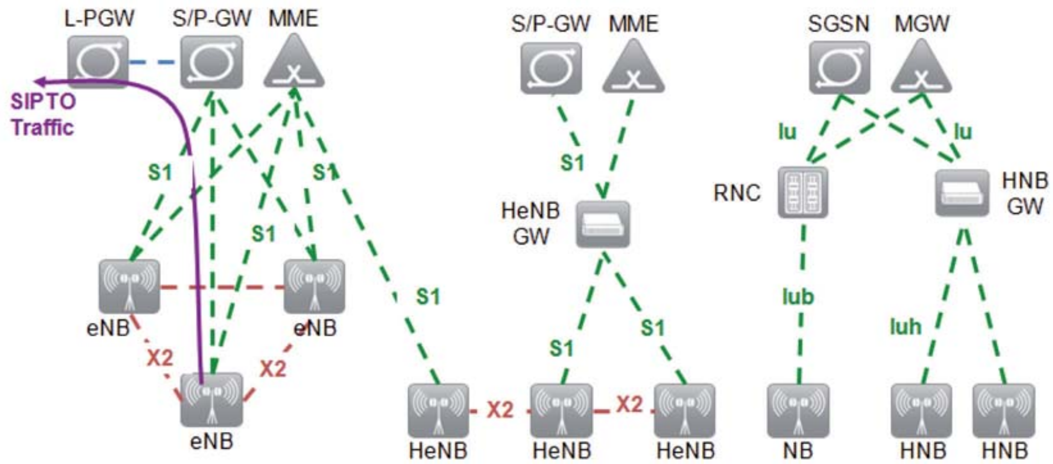

Figure 2: 3GPP LTE and UMTS Release 10 Architecture

3.1.3 Aggregation Gateway

As described earlier it is assumed that Small Cell base stations will support 3GPP compliant interfaces like S1, X2, Iub, Iuh, etc. However, for better scalability (e.g. reducing the number of logical S1 interfaces to be supported by the EPC) an optional aggregation gateway can be introduced to the architecture.

This optional aggregation gateway can provide functionality on user, control and management plane helping to reduce the signalling load on the core elements (e.g. EPC) as well as to ease operation of small cells. It will be based on the gateway architecture defined by 3GPP for Home NodeB (HNB) and Home eNodeB (HeNB) offering standard interfaces towards the core elements (S1, Iu). Although the Home Base station architecture was originally intended to support consumer deployed Home base stations (AKA femtocells), its use is not precluded for operator deployed small cell networks.

Depending on the capacity of the aggregation gateway (number of supported Small Cells) as well as the applied network topology it might be deployed within either the access or aggregation domain. A collocation with a Macro base station and supporting from 4 to 12 Small Cell BTS might be a reasonable configuration. The aggregation gateway might include also IPSec functionality to support IPSec tunnels towards small cell BTS as well as towards EPC.

3.1.4 Topologies

Assuming that the operator already has a radio network in place, a straight forward option is to connect the small cell base station directly to the macro cell site (or any other site offering connectivity to the existing backhaul network). From topology perspective this would look like a traditional hub-and-spoke, with small cells as spokes and the macro BTS site as hub.

Alternatively, e.g. in case of a greenfield deployment or when other transport services are more applicable from cost or availability perspective, the small cell base stations can be connected to any other transport network offering suitable backhaul services. The connectivity can be established either directly or via an aggregation site.

Optionally the hub point offering the connectivity to the cell sites could also be a dedicated aggregation site as shown in the lower half of Figure 3. In this case the node at the aggregation site has the connectivity to the existing backhaul network.

The connectivity between the small cells and the hub point (being either macro cell or aggregation site) could be based on point-to-point or point-to-multipoint topologies (independently whether wired or wireless connectivity is used). As a further option, instead of connecting every single small cell BTS to the macro site chain, tree or mesh topologies can be used between the small cell sites themselves for providing further connectivity.

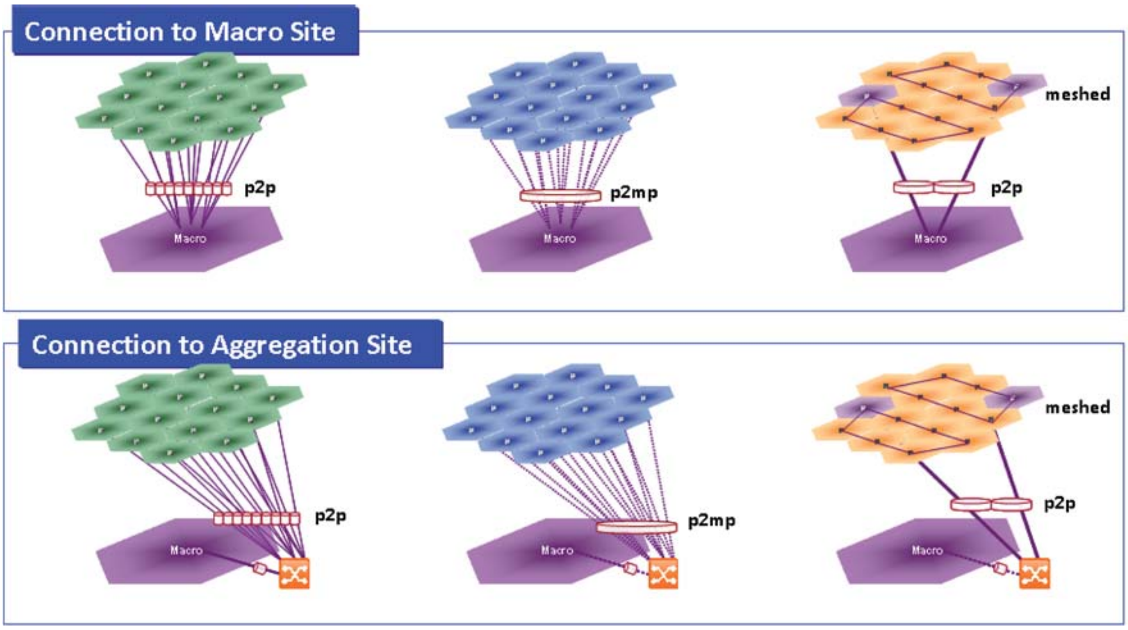

Figure 3: Basic connectivity options when using an existing macro cell layer

Mobile operators will most probably use a mixture of various backhaul technologies and architectures to provide transport connectivity to small cells in an effective way. In general the connection of the small cells could be done via wireless or wireline topologies.

3.1.5 Wireless topologies

Usage of traditional Line-of-sight (LOS) technology may restrict the coverage of wireless backhaul to small cells and potentially drive up costs if alternative paths need to be used. Near- or even Non-line-of sight options are therefore under consideration. A schematic overview of different application of wireless technologies are shown in Figure 4

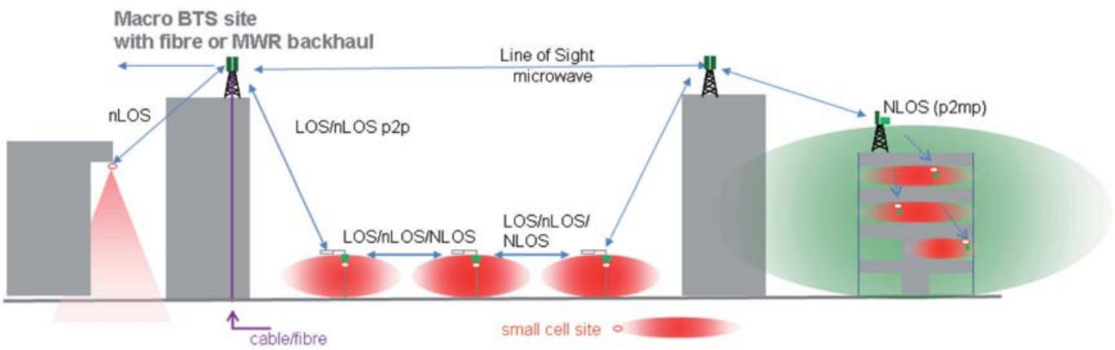

Figure 4: Potential wireless backhaul topology

There might be cases where specific small cells base station cannot be directly connected to the macro cell site via a single wireless link because of physical obstructions, but can be reached via another small cell BTS. In these cases more complex topologies like chains and trees could be used. Such topologies would require the small cell backhaul solutions to support multiple wireless links as well as a traffic aggregation functionality.

Connecting small cell base station via chains or even trees may be an appropriate topology when they are installed e.g. on lamp posts or any other place few meters above street level. In those cases it is sufficient that only one of the small cell BTS is connected to the backhaul network (e.g. via macro cell site) and further connectivity is provided among the small cell base station themselves.

The small cell layer might have connections to two different macro base station sites (called "dual attachment" as shown also in Figure 4) for resiliency reasons, i.e. if one of the connection goes down the other one could take over – but both are not used simultaneously.

Whilst multi-hop topologies can provide extensive connectivity, they may do so at the cost of capacity and latency performance. Requirements for these aspects are defined later.

3.1.6 Wire-line topologies

When using wired backhaul technologies for connecting the small cell base stations the same approach as with wireless option can be applied: Small Cell BTS are directly connected to an existing Macro Cell. However this requires that cables (i.e. fiber or copper) are deployed for this usage between the sites. A schematic overview of different application of wireline technologies are shown in Figure 5

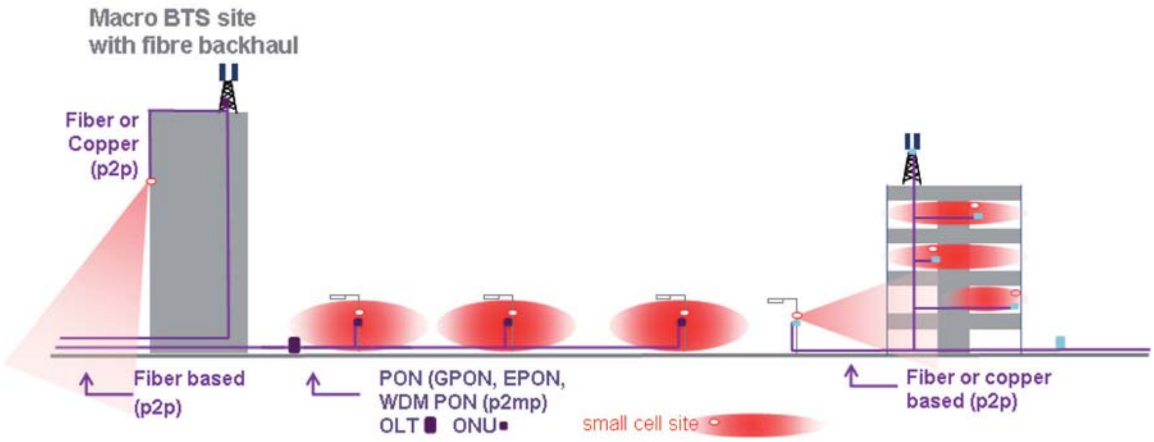

Figure 5: Potential Wireline backhaul topology

Optionally an alternative backhaul path can be used (e.g. via 3rd party network provider, ISP etc), where the connectivity into the mobile operator's network is made at a different point in the network. In this case also other transmission methods are applicable, like various PON or variants of DSL, depending on their availability at the small cell BTS site. For a non-incumbent operator's small cell the usage of fixed-line backhaul (via 3rd party service providers) depends on the service availability at the cell site, supported features and price level.

3.2 Physical Design / Hardware Architecture

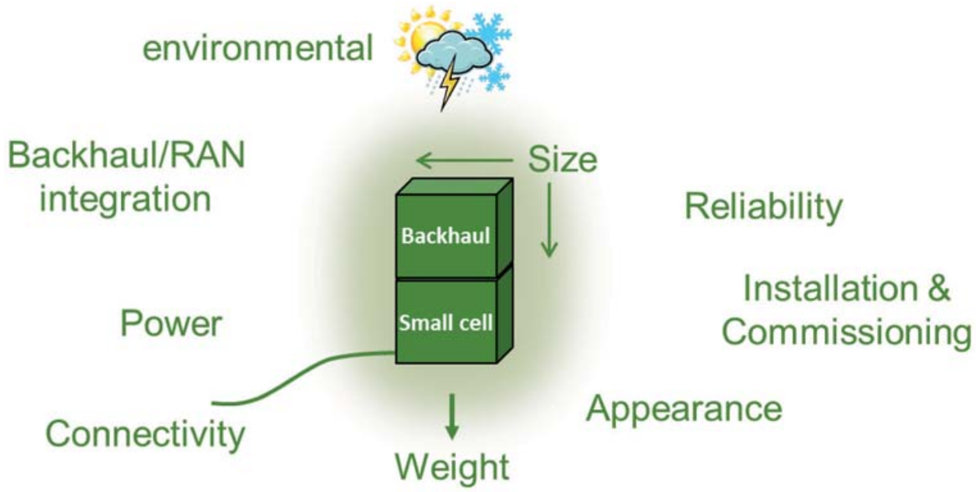

Figure 6: Key Aspects of Physical design requirements

Physical design is likely to be a key differentiator between the small cell solutions as it impacts the range of locations suitable for deployment and the cost of doing so. Figure 6 summarises aspects of the physical design for the small cell and associated backhaul unit. With perhaps the exception of the environmental protection, requirements are all more challenging for small cells than for macrocells.

Varying degrees of integration between small cell and backhaul unit are possible which impacts factors such as ease of deployment, size, security and flexibility, as illustrated by the following examples:

1) Fully integrated modules: Backhaul function integrated into RAN node with dedicated backhaul card (or vice versa). Full integration reduces vulnerability to tampering, reduces size and potentially eases deployment. Flexibility in selecting best in class RAN or backhaul units is compromised.
2) Two separate modules: Connections for data and power within a single physical enclosure so that the interconnections between the two are protected from the outside and it can be seen as a single volume.
3) Completely separated modules: Seen as two boxes from the outside and interconnections between two have to be protected both from weather and malicious interventions.

Figure 7 summarizes key issues for physical design and hardware architecture requirements. All of the requirements are ultimately driven by the need to achieve very low Total Cost of Ownership (TCO)

Considering environments where Small Cell Backhaul equipment will be located, the probability of an unauthorised person (general public) coming into physical contact with the equipment is much greater than for a traditional cell site. This means that physical contact must not create injury: i.e. secure mounting, electrical surge protection, safety cable connector locks, no sharp edges, and any other similar issues. Reduction of the risk for injury or damage has to be considered into Small Cell Backhaul hardware design.

Key Issues	Small Cell Backhaul Requirements	Macro Cell Backhaul Requirements	Resulting Solution Benefits
Equipment Form Factor and weight	Small in size, "one box" architecture (all outdoor) Minimum number of physical ports Unobtrusive appearance, "street furniture camouflage" Optional small cell integration, functional independence of RAN & Backhaul	In many cases Macro deployment is "out of sight" and less restricted in space. A requirement for support of legacy backhaul encourages split-mount modular architecture and high densities of physical interfaces.	Reduces the space used. Minimises the overhead of civil works permissions and site engineering. Reduces installation costs and rentals. Avoids negative public reaction.
Power Supply and Consumption	Mains power supply Support for Power over Ethernet Low power consumption, a fraction of what is required for the small cell	"Classic" telecommunication captive office specification for DC power. Performance and cooling needs requires higher power consumption.	Enables the deployment at the street level and minimises the cost & complexity of power supply
Installation Procedures	Lightweight equipment, easily mounted Single technician's task, fast procedures with little or no site preparation. Ideally one site visit for RAN and backhaul	Fully controlled and regulated site acquisition and engineering, less pressure for "instant roll-out"	Reduces the cost of installation and improves the speed of deployment
Commissioning Procedures	"Plug & play" with minimum training Automated provisioning	Fewer installations, traditionally performed by highly skilled "Telco grade" technicians	Reduces the cost of installation and improves the speed of deployment
Reliability and Maintenance	Resistant to shocks and vibrations Highly reliable in all weather conditions Easily replaced (maintains configurations)	Secured site environment allows a greater degree of protection against environmental conditions	Reliability and easy replacement lower the cost of operations.
Green Credentials	Goes above and beyond all commonly accepted standards on the use of materials	The same	Essential for Corporate Social Responsibility
Safe-to-touch	Safety consideration on an unauthorised person's (general public) contact with the small cell equipment	Normally located at restricted access area General telecommunication equipment's safety requirements.	Reduces risks of injury or damage to persons and/or things.
Risk of physical access	Protection from any types of intervention such as weather and malicious attack.	Normally located at restricted access area General telecommunication equipment's safety requirements.	Improves operational reliability & reduces any physical damage.

Figure 7 Key issues for physical design and hardware architecture

3.3 Coverage and Connectivity

In the context of small cell backhaul, coverage refers to the ability of a solution to extend connectivity out from PoPs (Points of Presence) to the small cell deployment locations. This connectivity must meet with the Quality of Service performance requirements described elsewhere.

Given that the primary deployment motivation is to enhance capacity of data services, small cells will typically be deployed in areas of high demand, such as city centres and transport hubs. Small Cells are expected to be located mainly outdoors at spacing's around 50-300m apart, at about 3-6m above street level. They may also occasionally be deployed on a rooftop or an indoor public space (sports arena or a shopping centre). However, the most common locations are likely to be street furniture such as lamp-posts, bus shelters and sides of buildings. The backhaul unit will likely be co-located, if not integrated with the small cell itself. Figure 8 illustrates typical deployment locations.

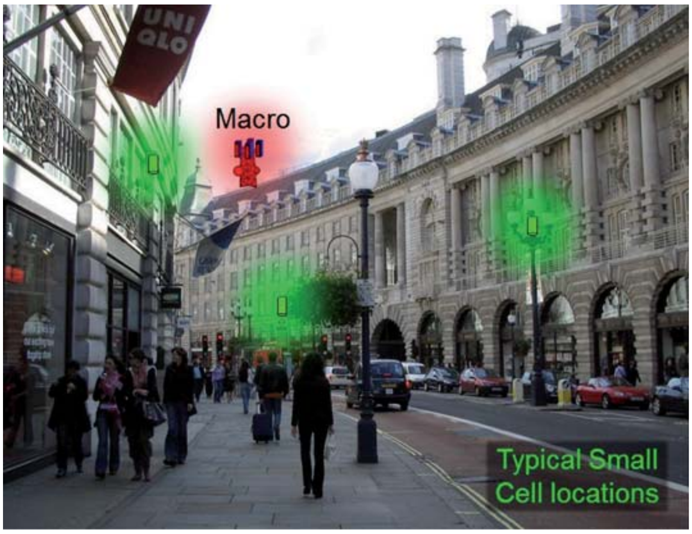

Figure 8 Typical Small Cell locations

Where small cells are deployed as a complement to macrocells forming a 'het net' (heterogeneous network), it is possible that the macrosites themselves will become the PoPs for small cell connectivity back towards the core. The coverage challenge in this case is therefore in connecting street level small cells to rooftop macrosites. Figure 8 shows possible locations for both macro and small cells.

Different backhaul technologies have very different challenges from the coverage perspective:

- Wired solutions have to reach the small cell sites along or below ground or within buildings. Coverage will be closely tied to the presence of existing infrastructure, since the costs of installing new wired connectivity is high.
- Wireless solutions require consideration of the propagation environment between backhaul transceivers at the small cell and PoP. In dense urban environments, there may not always be a Line of Sight between these locations, and so non line of sight or multi-hop approaches could be used to improve coverage, provided QoS can be maintained. Wireless backhaul adaptability may be important for NLOS solutions, since at street level the radio conditions can change frequently and dramatically (e.g. radio channel change by the pass of truck, trees leaves in spring, etc.) nLOS and NLOS technologies should be proven feasible for LTE rollouts.

3.3.1 Influence of backhaul coverage on cell site locations

All cell sites whether macro, micro or pico require each of the following:

a) Presence of traffic demand – i.e. many consumers wishing to use data services
b) Suitable site location, with power, access etc.
c) Backhaul connectivity
    - Existing wired infrastructure
    - Line of sight / good propagation to backhaul hub, or other nodes in a multi-hop topology

The ideal location from a coverage/capacity perspective (a) often needs to be balanced with the practicalities of available sites and backhaul connectivity (b,c). In the case of macrocells with a cell radius of several km, the site may be located within a few hundred meters of the ideal location and still satisfy most of the demand. For small cells covering localised 'hot spots' of demand, this locus of acceptable site locations is considerably smaller – a small cell may need to be within 10 meters of the ideal location. This 'targeted hot spot' deployment strategy for small cells therefore requires a very high level of backhaul coverage.

The targeted hot spot strategy assumes small areas of high demand density comparable in size to the coverage area of a small cell. It must also be the case that the hotspot will not move during the lifetime of the small cell. For example it may be associated with the entrance to an underground metro station or other permanent hot spot. Where the area of high demand is larger than a single small cell, or where the hotspots are associated with activities which may change over time (e.g. a café), a 'blanket' approach to small cell deployment may be more appropriate. Here a number of small cells are deployed across an area of high demand – for example alongside a shopping street. Whilst the blanket approach might not match the site locations to the demand peaks at the time of deployment, it requires less planning and allows more flexibility to available site locations and presence of backhaul coverage. A blanket approach would be facilitated by a large scale site leasing arrangement, for example with a municipality.

3.4 Capacity Provisioning

3.4.1 Overview

Here we describe a method to evaluate backhaul capacity provisioning for small cells, which is based on that used for the recent LTE provisioning guidelines [1], as follows:

- User-plane Cell Tput based on NGMN simulations of user throughput in urban macro cells scaled to represent the small cell environment
- Overheads added for transport protocol, security and X2 where appropriate
- Algorithm described to evaluate backhaul provisioning for aggregates of N cells

This is a 'bottom up' approach which considers the maximum cell throughput characteristics of each cell in the RAN, under light and heavy loading conditions. These figures are directly applicable to provisioning in the 'last mile' as defined earlier in Figure 1. Provisioning towards the core requires estimation of the aggregate traffic from a number of cells, for which a simple rule is provided. It is recognised that operators may wish to use different algorithms based on their own empirical data.

3.4.2 Scope of Capacity Provisioning figures

The NGMN have focussed on priority use cases for small cell deployments as described in a previous section. These impact the backhaul provisioning requirements as follows:

- Key deployment motivation is for capacity, so operators will be looking to utilise RAN capacity as much as possible. It should not be limited by the backhaul
- Capacity provisioning figures are most needed for:
    - LTE FDD 10MHz & 20MHz
    - HSPA 5MHz and 10MHz
    - WiFi 802.11x
- Combinations
    - Individual RAN technologies
    - LTE+HSPA
    - LTE+HSPA +WiFi
- Other Assumptions
    - Single band per technology only
    - Single operator per site

The intention here is to provide a generic set of provisioning figures for the key RAN technologies which can then be combined to and possibly scaled to represent an operator's particular technology and spectrum portfolio.

3.4.3 Components of backhaul traffic

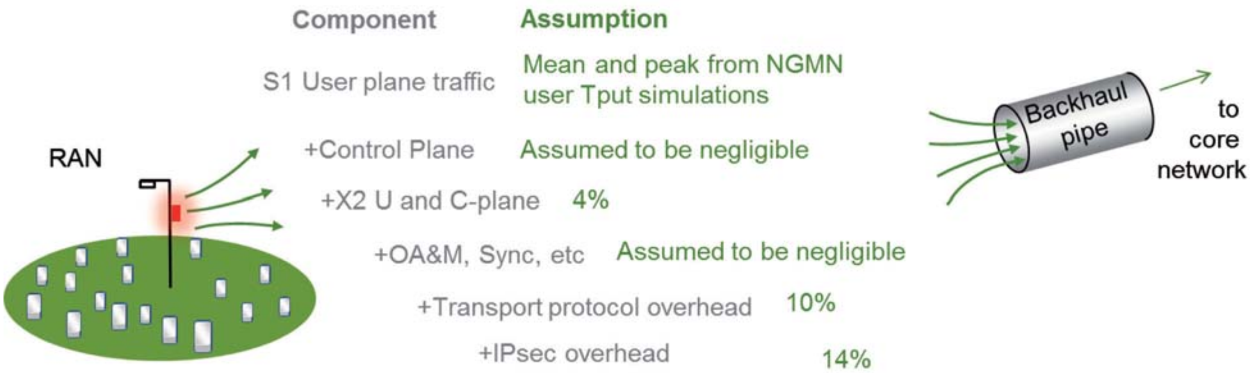

Figure 9: Components of LTE backhaul traffic and assumptions for overheads

Each small cell generates a variety of different traffic components which have to be backhauled, as shown in Figure 9. The majority of the traffic is the user plane data itself. Other components can be considered as overheads and are expressed as a proportion of the user plane traffic. It should be noted that the X2 is not supported for release 8 LTE Home eNodeBs, however in the absence of X2, and S1 handover would be performed and so provision would not be reduced significantly.

It should be noted that in practice, the level of overhead may vary with the traffic type. For example, a large number of low data rate connections (e.g. Machine to Machine) will have a higher proportion of signalling than a small number of high data rate users (e.g. file sharing). The figures here represent a mix of different traffic types, and are consistent with NGMN's previous LTE provisioning guidelines [1]

For HSPA small cells, we assume the Iu-h overheads to be similar to the Iub. Reference [6] gives an Iub transport overhead of 26% for ATM over IP, which assumes a large number (100) of MAC-d Protocol Data Units per frame protocol packet to represent a fully loaded NodeB.

3.4.4 User plane Cell Throughput and Cell spectral efficiency

User plane data is the largest component of backhaul traffic and its characteristics depend largely of the number of users sharing the cell's resource, and their positions. A detailed description of the mechanisms involved are given in [1], but can be summarised as follows: Cell throughput can be characterised under two different loading conditions, busy times and quiet times.

During busy times, there are many users sharing the cell's spectral resource. Since the users are distributed across the cell from centre to edge, they have varying signal quality and corresponding link spectral efficiency. The overall cell spectral efficiency is the average of all the supported links. Given the many users at busy time, it is unlikely they will all be in good or bad conditions. Cell spectral efficiencies are used to indicate the capacity of a radio network under full load. Here we use the term busy time mean cell throughput to characterise this condition.

During quiet times, there may often only be one user accessing a cell, and it can therefore use the entire spectral resource. If this user has a good quality link with the cell, then the overall cell spectral efficiency will also be high, and very high user (and cell) data rates are achieved. These are the conditions needed to achieve the 'peak rates' of a given RAN technology, and define the upper limit of cell throughput. Here we use the term quiet time peak.

Note that cell spectral efficiency and cell throughput are interchangeable, where the former is normalised to the channel bandwidth used by the cell, typically 5,10 or 20 MHz.

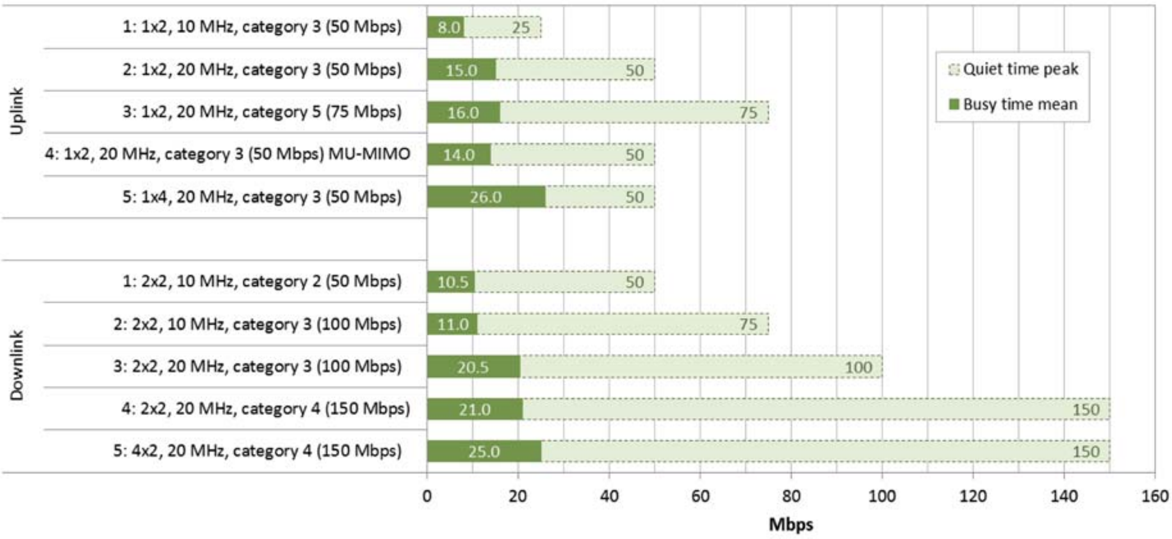

Figure 10 Mean and Peak User Plane Traffic per Cell for different LTE Configurations, source NGMN [1]

Figure 10 summarises busy time mean and quiet time peak user plane cell throughputs for a number of LTE uplink and downlink antenna configurations, system bandwidths and UE categories (with peak throughput in brackets). These figures are based on[1] and represent a simulation study undertaken by the leading equipment vendors within NGMN. Key assumptions are as follows:

- Urban Macrocell Environment (Interference limited)
- Inter site distance (ISD) 500m
- UE Speed: 3km/h
- 2GHz Path loss model: L=I +37.6*log(R), R in kilometres, I= 128.1 dB for 2 GHz
- Multipath model: SCME (urban macro, high spread)
- eNodeB antenna type: Cross polar (closely spaced in case of 4x2)
- User traffic model: fixed file-size transfer (as opposed to 'full buffer')

The peak figures given in Figure 10 represent the maximum device capability, whereas [1] used a 95%ile data rate from simulations. These figures are chosen to be more representative of the small cell environment where the conditions needed to achieving the peak rate are expected to occur more often than with macrocells. This assumption is made for both HSPA and LTE provisioning figures.

Similar figures were also produced for various HSPA configurations, and could if necessary be derived from the backhaul figures presented later in this document.

3.4.5 Spectral efficiency in small cells versus macro cells

Cell Tput results from the NGMN's simulations are based on a macrocell only environment. Small cells are expected to have higher busy time cell throughput for the following reasons:

1) A Uniform area distribution of users may be pessimistic for small cells deployed to cover a 'hot spot' within clusters of users. The resulting concentration of users towards the cell centre and away from the edge improves the signal quality distribution during busy times and increases cell throughput. This would not be the case where small cells are used to provide contiguous coverage.
2) Macrocell propagation may also be pessimistic. Small cells located 'down in the clutter' are likely to have better inter-cell isolation, reducing interference and improving the signal quality distribution, and thus cell busy time throughput

To provide numerical evidence of the above, 3GPP's feasibility study for LTE Advanced [7] includes an analysis of cell spectral Efficiency in the ITU defined macrocell and microcell environments [8]. The ITU-R environment definition for microcells aligns well with that used in this study for small cells. Figure 11 summarises cell spectral efficiencies for comparable MIMO configurations and CoMP schemes. Cell Spectral efficiency in the microcell environment is on average 25% higher than in the macrocell environment. Note that L=1,2,3 refer to the number of OFDM symbols allocated to the downlink control channels, and represent the degree of user traffic to control signalling needed. Variations for different schemes and control overheads are all within a few per cent of the average. We therefore assume that small cells will have 1.25x higher cell spectral efficiency than macrocells.

Note that these simulation results apply to macro-only and small cell-only deployments in a given channel. If both macrocells and small cells are deployed in the same channel, then the average cell spectral efficiency would lie somewhere between the two extremes, depending on the proportions of macro and small cells in the mix.

	Urban Microcell			Urban Macrocell						
Scheme and antenna configuration	Cell average [b/s/Hz/cell]			Cell average [b/s/Hz/cell]			Ratio Micro:macro			average
	L=1	L=2	L=3	L=1	L=2	L=3	L=1	L=2	L=3	
DL MU-MIMO 4 x 2 (C)	**3.5**	**3.2**	**2.9**	**2.8**	**2.6**	**2.4**	**125%**	**123%**	**121%**	123%
DL CS/CB-CoMP 4 x 2 (C)	**3.6**	**3.3**	**3.0**	**2.9**	**2.6**	**2.4**	**124%**	**127%**	**125%**	125%
UL Rel-8 SIMO 1 x 4 (C)	**1.9**			**1.5**			**127%**			127%
										125%

Figure 11: Comparison of cell spectral efficiencies in ITU-R Macrocell and Microcell environments [8]. Source 3GPP [7]

The 1.25x scaling figure applies to the busy time mean as it is dictated by the signal quality distribution. The scaling is not applied to the quiet time peak as it is limited by the technology. A small cell will typically cover fewer users than a macrocell, and so the quiet time peak conditions (single user per cell) are likely to be more prevalent.

3.4.6 Single Small cell backhaul traffic HSPA and LTE

Figure 12 and Figure 13 show busy time mean and quiet time peak backhaul levels for various configurations of HSPA and LTE small cells and UEs. These include the user plane traffic and the various overheads. It can be seen that the overheads result in backhaul traffic higher than the peak device capability.

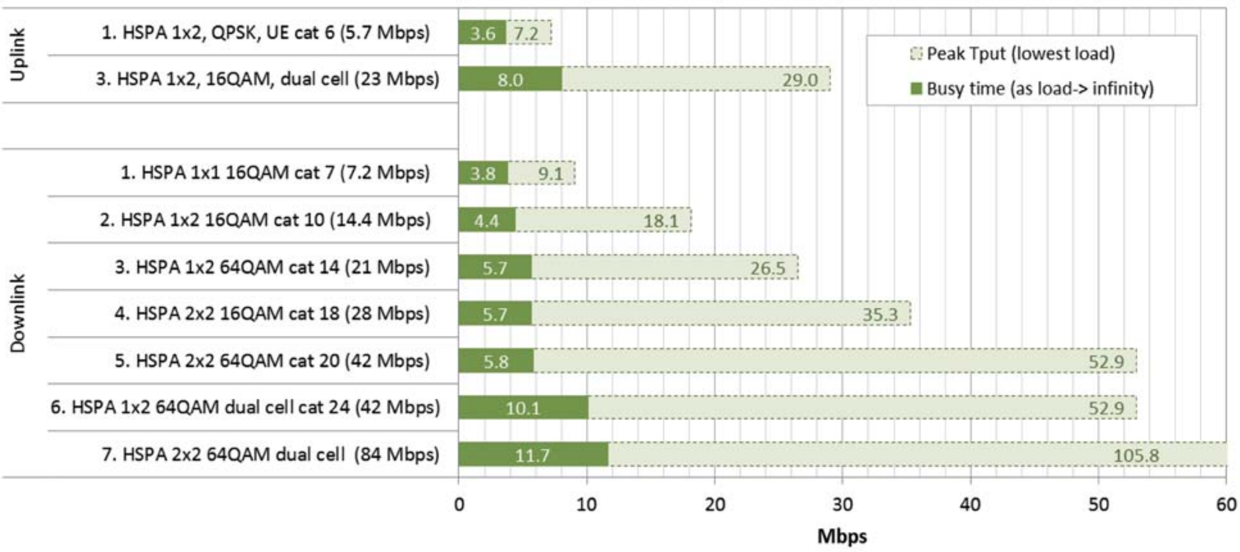

Figure 12: Backhaul Traffic Characteristics HSPA Small Cells in various configurations

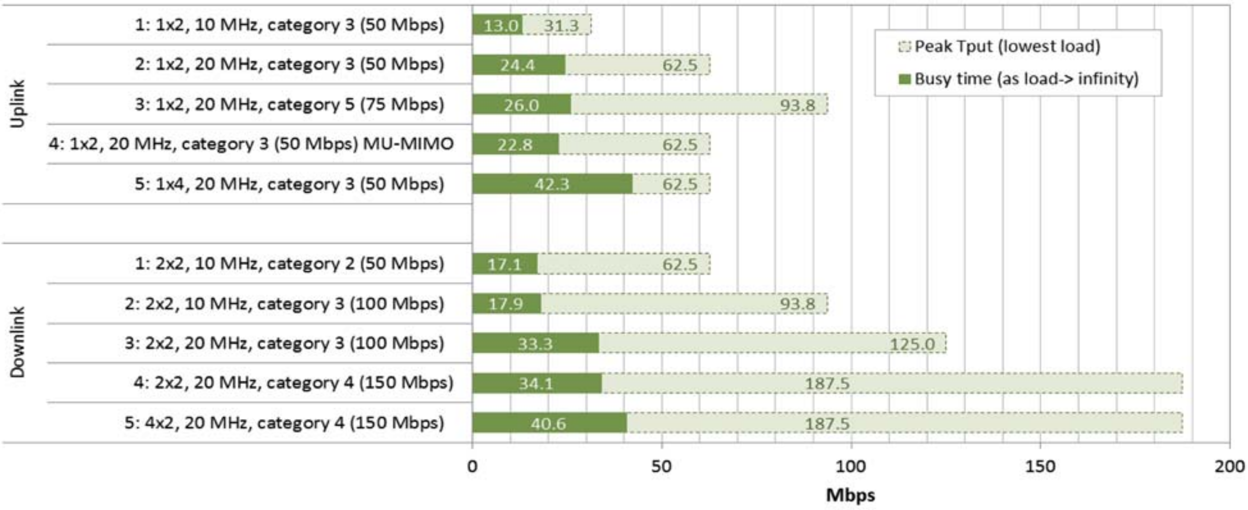

Figure 13: Backhaul Traffic Characteristics for LTE Small Cells in various configurations

3.4.7 Wi-Fi Provisioning

Although WiFi operates at lower spectral efficiency [9] than HSPA or LTE, a WiFi access point in the 2.4GHz ISM band can potentially use an entire 85MHz of unpaired spectrum, much larger than the 10-20MHz for a 3GPP small cell in a licensed band. Although high end WiFi units have been measured to deliver peak throughputs of 80Mbps [10], the more stable units suitable for long term operator deployment are likely to have lower capacity. Furthermore, the contention based medium access control (MAC) is inefficient at high loads due to increased numbers of collisions [14,15]. One NGMN operator member provided a backhaul traffic profile for an operator managed public WiFi hot-spot. This typical traffic profile shows a 2Mbps mean and a peak of 8Mbps.

3.4.8 Provisioning for the Quiet Time Peak

Compared to macrocells, small cells have fewer users with more tendency to cluster around cell sites. This increases opportunity to achieve peak throughputs. Peak user Tput may therefore be backhaul rather than air interface limited. Peak provisioning is an operator choice, they may not want to provision as much as the UE device capabilities given here. The peak rate capability may be driven by marketing rather than engineering - statements like “up to XX Mbps” attract consumers, and would need to be supported by the backhaul. Operators will also need to trade this against potential increases in TCO caused by overprovisioning.

3.4.9 Multi-site / technology provisioning

A simple estimate of the total aggregate traffic for N small cells can be based on the following algorithm used in the LTE guidelines [1]: Multiple ‘cells’ of different technologies may exist at one site (HSPA, LTE, WiFi, GSM etc.)

Provisioning for N cells = Max (peak, N x busy time mean)

This assumes that during busy time, the total traffic for N cells is simply N x busy time mean. During quiet times, peaks are assumed not to occur simultaneously across a small number of aggregated cells. For large aggregates the overall provisioning for the busy time will be the dominant factor, and will significantly exceed the peak for any one cell.

Individual operators may wish to use a more sophisticated method of calculating total aggregate provisioning, which takes into account ‘statistical multiplexing gains’ - the probability that not all cells will be simultaneously busy. Further descriptions of such mechanisms can be found in [1]. The algorithm given may be used to evaluate provisioning for both multiple sites and multiple technologies at those sites, by summing the appropriate busy time mean and/or quiet time peak figures for the different technologies.

3.5 QoS Support

In the context of this backhaul study, Quality of Service refers to the performance of the connectivity for all user, management and control plane traffic, which may include (but is not limited to) the following:

- Data rate
- Packet Delay (latency)
- Delay variation (jitter)
- Packet loss
- Connection setup time
- Connection availability
- Connection drop rate
- Connection interruption times (e.g. during handover)

The purpose of QoS support is to ensure a connection has sufficient performance to ensure a good user experience when using a particular service. For voice, low delay and jitter are important, whereas for file transfer, data rate is the main measure of performance, and latency and jitter matter less (provided they do not impact data rate). QoS support by the infrastructure is needed during times of congestion, and are essentially prioritised packets in queues according to their data flows to ensure their particular performance requirements are met.

Performance is impacted by all segments in the end to end connection between the user and their data source, which could be a web server or another user in the case of telephony. The backhaul segment typically provides support for a small number of CoS (Classes of Service) onto which multiple different levels of QoS can be mapped. Depending on nature of deployment (use case scenarios clarified before) QoS parameters will vary widely. We consider here the use case scenarios presented earlier:

1) Best-effort data offload for 3G macrocells
2) Early move to LTE small cells with full service offering

In the case of scenario 1 QoS handling is still required for the backhaul to ensure sync, signalling and management plane traffic are prioritised. No differentiation is needed for the User plane traffic. In Scenario 2 where both real time and non-real time applications need to be supported, small cell backhaul must support the same level of user plane QoS differentiation as with macrocells, as follows:

a. Mechanism to ensure prioritisation of real time flows (e.g in case of congestion) in support of fulfilling E2E performance requirements.
b. Backhaul congestion status may be used as an input to the RAN scheduler.
c. Support for congestion mitigation techniques.

The view of the NGMN operators is that users should have the same *Quality of Experience* whether accessing over small cells or over macrocells. This does not mean that the offered Quality of service has to be the same as macro cells as shown in Figure 14.

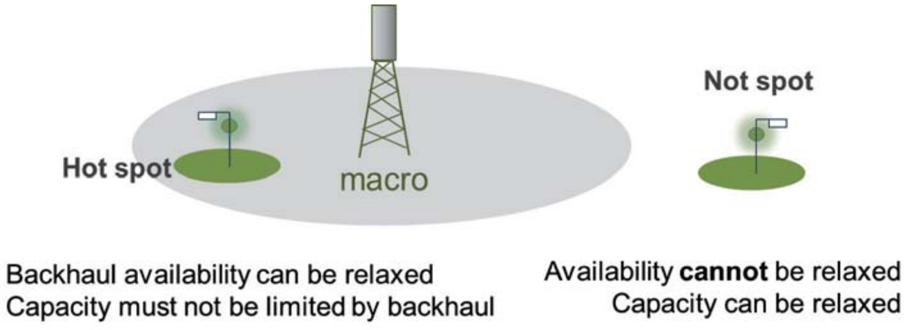

Figure 14: Possible QoS Relaxations depending on the deployment scenario.

Small cells deployed to provide capacity at hot spots may have relaxed backhaul availability as the macro-layer coverage can act as a 'safety net'. In this scenario, the busy time capacity of the small cell RAN should not be limited by the backhaul. Conversely, small cells deployed to provide coverage to 'Not Spots' must have the same backhaul availability as a macrocell, yet the capacity may be relaxed.

Operators are expected to map the QCI (Quality Class Indicator) parameters, defined for different types of service, into a set of values/ QoS profiles that are backhaul related for the sake of different flow handling (e.g DSCP, TOS, P-bit).

3.6 Synchronisation

Frequency synchronisation is needed by HSPA and LTE basestations to ensure stability of the transmitted RF carrier. This is in part to ensure the transmitted signal sits exactly within the allocated channel to comply with license conditions, and also is a requirement to have a successful handover between cells. In TDD systems, the more challenging *phase* synchronisation is additionally needed to ensure uplink and downlink transmissions in adjacent cells do not coincide. Interference co-ordination such as CoMP in LTE-Advanced also requires phase or time of day synchronisation [16]

Synchronisation can be achieved using a timing source at each base station, such as Global Navigational Satellite System (GNSS), or it can be achieved by dedicated signalling over the backhaul.

GNSS based synchronisation provides suitable frequency and phase accuracy, however it can be vulnerable to signal loss if the receiver is used indoors or due to a malicious jamming attempt. Since the main use case discussed in this report is for an outdoor small cell and 3-6 meters above street levels, GNSS is an option.

Synchronisation over packet switched (Ethernet or IP) backhaul is more of a challenge than with legacy circuit switched (e.g. E1 or STM-1) connections. Several technologies have been defined to allow the basestation to extract synchronisation from a remote clock reference including IEEE1588v2, NTP and synchronous Ethernet. These methods provide frequency synchronisation needed for basic FDD LTE, although not all methods can provide phase synchronisation needed for TD-LTE or CoMP.

The backhaul should be designed to carry synch packets to the basestation so that the minimum requirements set by 3GPP 25.104 (3G) 36.104 (LTE) for small cells (Local Area BS) in terms of frequency accuracy (at least ±0.1 ppm) and phase accuracy for TDD system (± 1.5 us) are met. 3GPP defines home, local and wide area base station classes based on minimum coupling loss experienced between the UE and base station (how close a UE can get to the base station). The local and home classes have restricted power, but also relaxed requirements for frequency stability.

QoS prioritisation is likely to be needed to expedite forwarding of synchronisation packets, which would otherwise experience variable delays due to queuing. Different synchronisation technologies vary in terms of their sensitivity to delay and delay variation (jitter). However femtocell technologies have demonstrated that synchronisation is still possible over the public internet.

3.7 Availability and Resiliency

The design considerations for the packet-based transport for a Small Cell deployment are confined by the ability of that network to meet the proper levels of availability (the proportion of time a system is in a functioning condition) which is supported by the means of resiliency (the ability to readily recover) . The approach to benchmark of the Mobile Backhaul and IP/MPLS Core networks (as shown in Figure 15) has been to use the traditional voice call measuring methods such as Six-Sigma and/or 99.999% availability. Typically, packet-based transport networks are required to meet the 99.999% availability in order to have the same level of resiliency as compared to the original SDH/SONET networks which connect the Macro Cell nodes although, the availability numbers for Mobile Backhaul network may range between 99.9% - 99.99% due to the availability requirements from the Macro and Small Cell radios. In addition, certain types of data services may be able to support a lower availability compared to video/voice services if there would be a lower perceived impact to the Quality of Experience (QoE).

As the Small Cell deployment use cases are considered (HotSpot within Macro Cell; NotSpot outside Macro Cell), the availability and resiliency requirements will differ between the transport networks, "last-mile" services, and deployed radios. Since most Small Cell radio coverage will reside within an existing Macro Cell network (HotSpot), the Small Cell design will allow the user end device (UE) to failover/failback to/from the encompassing Macro Cell radio infrastructure. With this type of deployment scenario, the level of availability and resiliency requirements are affected as depicted in the Figure 15.

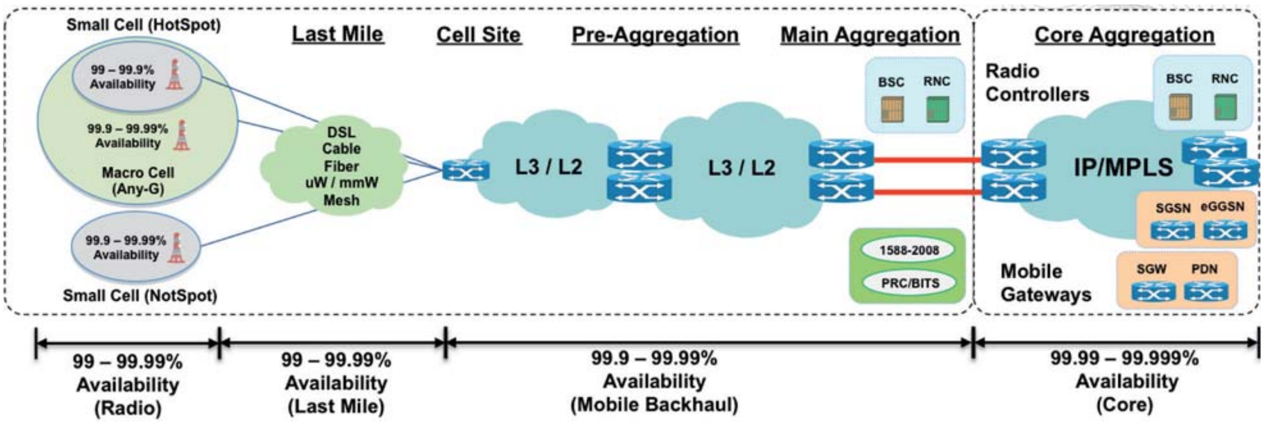

Figure 15 Availability on each section of the end to end connection

When the 'Hotspot' Small Cells are deployed to ease congestion from the Macro Cell radio and their coverage overlaps, the availability and resiliency requirements of the Small Cell can be reduced (99 – 99.9%) since the Macro Cell is able to support a higher available radio service (99.9 – 99.99%) during a Small Cell failover. With this lower availability requirement, operators and vendors can consider cost reduction options such as lower margins for atmospheric absorption (giving longer ranges) or using hardware without redundancy. When the 'NotSpot' Small Cells are deployed outside the macro cell radio coverage, a higher availability requirement is needed (99.9 – 99.99%) since there is no macro cell coverage for failover/failback.

The Small Cells' first backhaul connection or 'Last Mile', may use any of the following technologies.

- Digital Subscriber Line (DSL)
- Data Over Cable Service Interface Specification (DOCSIS / Cable)
- Fiber Plant Infrastructure
- Microwave Radio (uW) and Millimeter Radio (mmW)
- Multilink PPP (Bundling of E1/T1 into a Single Logical Connection)
- Self-Organizing Network (SON) Mesh Radio Systems

Availability is impacted by equipment failure, power outages etc. Redundancy could be implemented in the last mile to mitigate these, but is unlikely due to the requirement for low cost, and the potential relaxation of availability for hot spot applications. In wireless systems, availability may further be reduced by link outages caused by blockages (busses) pole oscillation, or atmospheric absorption (heavy rain). Mesh topologies offer additional resiliency where multiple connection paths exist.

The last mile backhaul provides connectivity on to the aggregation and core transport network. The aggregation and core transport networks should support an availability that is greater than or equal to the aggregate availability numbers for the "Last Mile" and Small Cell. The means for the Mobile Backhaul and IP/MPLS Core to support the availability requirements could be provided by the following resiliency Layer3 (L3) and Layer2 (L2) methods:

- IP/MPLS Traffic Engineering Fast Re-Route
- Gateway Redundancy Protocol (Virtual Router Redundancy Protocol / VRRP)
- ITU-T G.8032 Ethernet Ring Redundancy
- 1:1 /1+1 RFC 6378 "MPLS Transport Profile (MPLS-TP) Linear Protection"

- Linear Trail and SNC ITU-T protection schemes as defined in Recommendation G.808.1
- Pseudowire Redundancy

In conclusion, the topic of availability (proportion of time a system is in a functioning condition) will have different requirements in separate sections of the end-to-end implementation of a mobile operator's radio and transport infrastructure and the topic of resiliency (the ability to readily recover) will be supported by multiple transport means. The means to which to provide resiliency will depend on the required availability starting at the radio (Small Cell or Macro Cell) towards the Mobile Backhaul and IP/MPLS Core networks.

3.8 Security

3.8.1 Physical/equipment Security

The main difference between the macro and the small cell case is the latter is considered to be more exposed to attacks, being deployed outdoor in easy-to-tamper locations.

Depending on the level of integration between the small cell and the transport equipment the level of exposure to attack can be either emphasized or mitigated. In general the physical decoupling of the two functions in two separate boxes (first case on the left of the picture) tends to increase deployment flexibility, whilst opening some potential issues on security. For example, the interconnection cable between the two could be more easily unplugged (and, at least in theory, mis-used by a hacker).

The integrated case (last example on the right) tends to provide a higher degree of network security (e.g. a hacker cannot intercept the network cable connecting the two), decreasing the overall flexibility offered by the solution

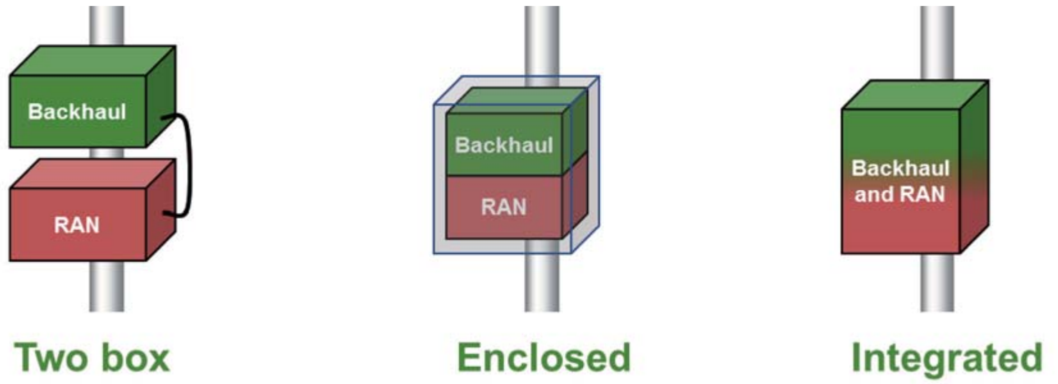

Figure 16: Levels of integration between a small cell and a transport equipment deployed in the same outdoor location

So, in terms of physical security it is expected that some form of hardening can be found in field (e.g. one single enclosure protecting both small cell and backhaul hardware, minimal power and data cable accessibility to non authorized people).

3.8.2 Network security

As for the macro case described in the NGMN's Optimised Backhaul Requirements document [1], the assumption is the small cells service model is described by 3GPP in their specifications.

Specifically for network security, the assumption taken in this analysis is the backhaul network is considered trusted, that is in accordance with relevant 3GPP recommendations (see, for example, [3],[4]) that foresee the adoption of the IPsec framework.

As for the macro case, an operator is free to enable or not the IPsec framework, but it is worth noting that standard security mechanisms available in current networks can just mitigate some potential vulnerabilities, leaving the door open to security breaches on both the small cell and the backhaul node.

Assuming then the IPsec framework is enabled end-to-end, a general security architecture is shown in Figure 17. This case refers to the first of the three cases shown in Figure 16 ("Two box" approach), but can also be associated to the second case ("Enclosed").

As the two functions are physically decoupled one or more connection cables are present over which the data traffic is exchanged. To help protect the backhaul network from attacks (or even simple mis-configurations) the backhaul function should implement some security mechanism to filter traffic and verify source and destination.

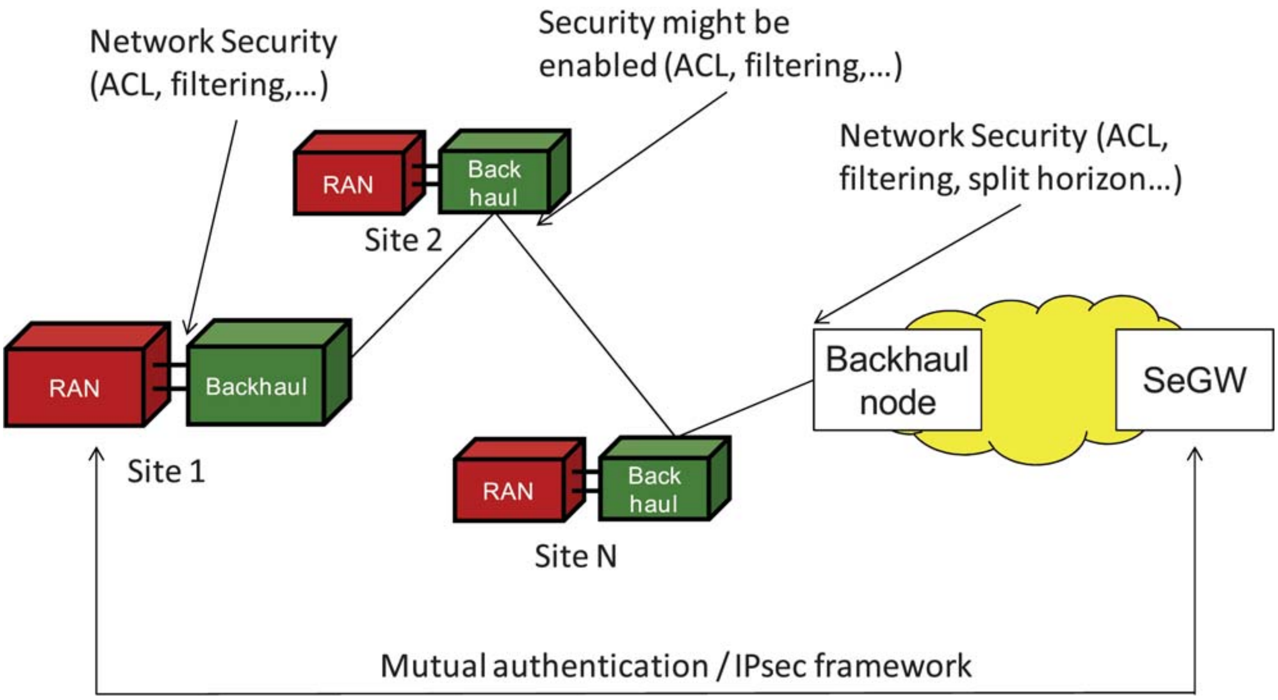

Figure 17: Security implementation for the "Two box" approach

As said, the picture represents the case where the two pieces of equipment are decoupled. In other cases some security mechanisms may not be enabled: for example, in the "Integrated" approach the transport module could be physically located within a small cell, so that mechanisms similar to those shown in the picture might not be needed. Among the security mechanisms that may be found in backhaul elements we have Access Control Lists (ACLs), traffic steering, traffic filtering, etc.

Independently from that, the IPsec framework, comprising data integrity, authentication and confidentiality is shall be always considered enabled to protect all flows exchanged by a small cell with the packet core through a Security Gateway (SeGW), at least for the LTE case. In other terms, whilst an operator has the flexibility to enable or not the 3GPP model based on IPsec in the macro case, for the small cells case that should be always enabled to guarantee the end-to-end service protection.

Specifically, a mutual authentication is enabled by any small cells and the core elements, based on the IPsec framework. IPsec is also enabled to support data confidentiality and integrity.

A discussion on the locaiton of the SeGW in the network topology can be found in the NGMN publication "Security in LTE backhaul" [17]

3.9 Operational, Management, Traffic Engineering

Small Cells present a particular environment in terms of operations, as they will often be located in difficult-to-access locations, and have a form-factor that complicates on-site operations. Furthermore, it's also likely that many sites will combine 3GPP and WiFi network access elements, and their sheer number will push operators towards a deployment and operations model that is as simple as possible. Finally, IPsec is expected to be used in most cases, which means that an additional bidirectional transport relationship must be established as part of the initial configuration.

In order to address this special situation, backhaul solutions for small cells must be able to provide sufficient O&M features in order to monitor their operation, update the firmware and troubleshoot the network remotely. These features must also be available in the case where more than one access element (base station) is connected to the backhaul at a single site.

Another area that requires specific developments beyond what is currently available for macro networks is having a pre-provisioned backhaul end-node and eventually RAN transport card that can be deployed without needing specialized skills. In this domain, the introduction of auto-configuration features and configuration files recovered from a centralized location may be useful.

On one point the requirements for small cells are less stringent than in the macro case: there is no need for traffic aggregation/differentiation between multiple operators, as the RAN sharing case is out of scope for the small cell deployments studied by the NGMN.

Finally, and given the rising importance of end-to-end QoS, it is also desirable that the adapted transport solution provides the means to verify on-demand and/or pro-actively monitor packet delay, jitter and loss rate over the backhaul network segment. For this, standard protocols (e.g. ITU-T Y.1731 and TWAMP/OWAMP (RFCs 5357, 4656)) are preferred.

4 Types of Small Cell Backhaul Solution

This section outlines different types of solution that have been proposed for backhauling small cells. The main objective of this white paper is to identify consensus around the technical requirements, rather than recommend particular types of solution. The selection of a solution also requires consideration of commercial factors which are beyond the scope of this study.

A currently held view is that the diverse conditions for small cell deployment will require operators to work with a 'toolbox' of solutions, as illustrated in Figute 18

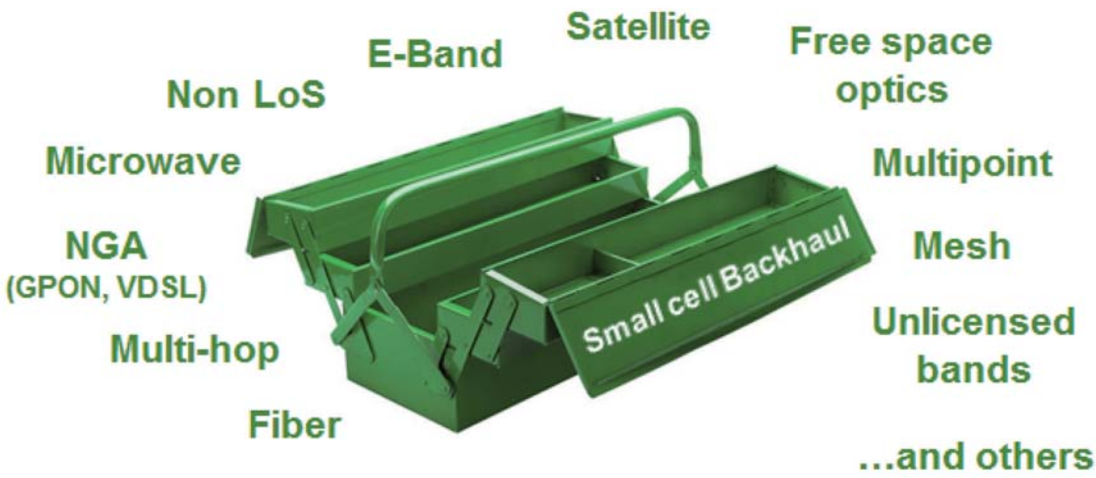

Figure 18: Diverse conditions are likely to drive a 'tool box' approach to solutions

Wireless and Wired solutions
Wireless backhaul has the advantage of not needing to run cabling between locations, which requires dealings with landowners along the route. Wireless solutions need only equipment at the small cell and point of presence, which can help reduce costs and improve the speed of deployment. A wired link is generally more predictable than a wireless, and where fibre is used, the potential capacity is much higher.

4.1 Wireless backhaul

Wireless solutions are differentiated by the propagation between sites, the spectrum used and the topologies formed by the resulting network.

Line of Sight and Non line of sight
A wireless backhaul solution with non-Line of Sight (NLoS) or near-Line of Sight (nLoS) capability means that the PoP does not need to be visible from the small cell, since the link can cope with radio signals penetrating through or diffracting around obstacles in the path (e.g. trees leaves). We differentiate between NLoS and nLoS in the sense that the main signal contribution in the NLoS case is from a signal penetrating an obstacle before reaching the link receiver. In the nLoS case the signal is able to reach the receiving end via diffraction around one or more buildings. NLoS is generally only practical with carrier frequencies below 6GHz, and not at 'microwave' frequencies in the 10's of GHz where penetration losses are significantly larger. It should be noted that the limited low frequency spectrum suitable for NLoS propagation is sought after for mobile access, more spectral bandwidth is available at microwave frequencies, giving the potential for higher capacity

NLoS solutions potentially offer better coverage in dense urban environments, provided the links support sufficient throughput to be usable. Antenna alignment is not needed for NLoS, simplifying installation. LoS Coverage in urban environments requires propagation down streets or 'urban canyons', but provides high capacity connectivity where available.

Spectrum licensing
All wireless solutions require spectrum to operate, and various different licensing arrangements exist:

- **License Exempt** – (e.g 2.4GHz and 5GHz 'Wi-Fi' bands, 60 GHz millimeterwave band). 'Free' spectrum can help reduce costs of a backhaul system, provided link quality of service requirements can be met. The license exempt bands can be heavily used in areas of high traffic demand for WiFi, Bluetooth and other applications. Such signals could potentially interfere with a backhaul solution sharing the same spectrum and impact its performance.
- **Link licensed** (e.g. point to point) – regulators license spectrum for specific links, with constraints on radiation patterns at specific locations in order to manage co-channel interference. Point to point microwave links are managed this way.
- **Area licensed.** A licensee may transmit (within given power limits) anywhere within a defined area, which could be a country, or a smaller region thereof. Whilst the onus is on the licensee to manage co-channel interference between transmissions, this provides more flexibility for a faster rollout without the need to request spectrum for each link. Mobile Radio Access Networks and Multipoint microwave systems are managed this way.
- **Light Licensed.** Spectrum can be licensed via a simple and quick application process at a nominal cost [12].

Carrier Frequencies
The carrier frequency used for wireless backhaul has a considerable impact on the coverage vs. capacity trade-off, as well as how the wavelength impacts the antenna design and cost of RF components

- **'Non Line of Sight' <6GHz (λ>5cm)**. Good coverage from Non LoS propagation, but generally require omnidirectional antennas with low gain as alignment is not possible. Capacity is limited by spectrum bandwidth, which is also highly prized for mobile access. Region wide area licensing for long durations (as per mobile spectrum) or License exempt bands such as those used by WiFi
- **'Microwave' $\approx$6-60GHz (λ 5cm – 5mm).** Predominantly LoS propagation, with some near LoS at lower frequencies. Short wavelengths enable compact high gain directional antennas suitable for long range fixed links, but resulting narrow beamwidths do require alignment on installation. Sector antennas also possible for point to multipoint topologies. Link and area licensing are common. Typically High availability and high capacity.
- **E-Band 60-80GHz (λ~5mm)**. LoS propagation only, with high atmospheric absorption limiting range but also reducing interference. Short wavelength enables very compact high gain and narrow beam antennas which require careful alignment. Several GHz-wide bandwidths available, enabling very high capacity even with robust low order modulation schemes. Light licensing schemes exist in many regions to encourage uptake of this new technology.

Wireless Topologies
Networks comprise multiple radio links between the small cells and the point of presence. The network topology defines the way these are connected

- **Chain, Tree or Ring**: Individual point to point links can be joined together to make a daisy chain or tree topology. Traffic is aggregated towards the PoP, and link capacity and resiliency increased depending on the number of downstream cells must be supported. Rings include redundant links which improves resiliency to link outages
- **Point to Multipoint**: A hub transceiver forms multiple links to a number of small cells. The total hub capacity is shared across the small cells, so statistical multiplexing gains are realised where traffic characteristics allow.
- **Mesh:** nodes in the network form multiple redundant links to improve resiliency. Sophisticated routing algorithms are used to find the lowest 'cost' path through the mesh, which may change with network loading as well as link outage.
- **Multi-Hop**. This refers to any small cell-PoP connection that passes over multiple links, and is implicit in mesh, chain, tree and ring topologies. Latency performance is impacted for nodes that are many hops away from the hub site. Capacity can also be reduced as links towards the PoP must aggregate traffic from multiple cells and may become a bottleneck. This is mitigated to some extent by gains from statistical multiplexing.

Satellite backhaul is well suited to providing coverage to isolated not-spots in rural areas where no local access is available. The solution provides good country wide coverage to outdoor locations, but the relatively high cost per unit capacity may impact its competitiveness against other solutions in a dense urban environment.

4.2 Wired backhaul

Wired connectivity could be copper or fibre: The xDSL family of modem technology utilises legacy copper twisted pair telephone infrastructure and can achieve throughputs of hundreds of Mbps, although only at line lengths less than 0.5km [5]. 50Mbps is achievable at 1km line lengths, which is sufficient to support HSPA small cells, but would truncate peak throughputs for most of the LTE configurations described earlier. Fibre provides a very high performance connection with multi Gbps throughputs possible with GPON (Gigabit Passive Optical Network) technologies.

Operators without existing wire line assets may elect to install or lease lines. Installing any wired infrastructure can be costly and time consuming, due to civil works and legal arrangements with landowners en route.

A leasing arrangement can make use of an extensive deployment of twisted pair copper and an increasing presence of fibre. Data rates from xDSL based technologies are sufficient for HSPA small cells, and those over fibre are approaching speeds suitable for LTE. For example, one provider promises an 80Mbps downlink connection in 2012 [13]. This is suitable to cope with the peak traffic from a10MHz LTE small cell, or could support loaded rates of 20MHz LTE, with truncation of peak speeds. Leased lines are intended to provide a generic service for wide range of applications and may be limited in the backhaul specific features they provide – The service described in [13] has only basic QoS support, and no mention of sync support is made. Connectivity is typically to the internet, whereas operators require connection to a dedicated handoff to their core network. Extending coverage to new sites requires new cabling which is likely to be more time consuming when conducted by a third party than if performed by the operator themselves.

5 Summary

Through a consideration of the way in which small cells are likely to be deployed by operators, we have analysed implications for the backhaul solution and developed a set requirements. The table below summarises key aspects of how requirements for small cell backhaul differ from that of macrocells. Based on the issues raised, requirements statements from NGMN's macrocell orientated '*Optimised Backhaul Requirements*' [11] have been modified and augmented to produce a set for small cell backhaul. These are captured in the Annex

Table 2 Summary of Requirements and comparison with those for Macrocell backhaul

Aspect	Small Cell Requirement compared to macrocells
Architecture	Support of 3GPP interfaces similar to macrocells. Aggregator nodes may be used.
Physical Design	Small & light to enable easy installation in street level locations, touch safe
Coverage and Connectivity	Last mile coverage to small cells at street level as opposed to rooftop
QoS Support	User experience should be same on small cells as on macrocells: Connection quality/performance no different to macrocell backhaul
Capacity Provisioning	Higher spectral efficiency, but fewer cells per site: lower mean throughput during busy time than a macrocell but similar peak. i.e. burstier traffic
Availability and Resiliency	When used to enhance capacity of a macro layer (i.e. overlapping coverage) lower availability of small cell backhaul is acceptable
Synchronisation	Relaxed frequency synchronisation requirements for the lower power base station classes. Stringent phase sync requirements for some deployments (e.g. LTE TDD). Similar backhaul synchronisation support requirements as for macro.
Security	IPsec mandatory when the backhaul is not trusted due to vulnerability of small cells to tampering
OAM	Large numbers of small cell connections mean consolidated mass-management is all the more important.

In addition to the backhaul requirements, a non-exhaustive set of solutions have been captured to illustrate how different types of solution are suited to different types of deployment. The diverse set of use cases suggest that operators will likely need to work with a 'toolbox' of solutions for their small cell backhaul.

6 References

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7 Annex: Requirement Statements

Requirement Statements (RS) are given in the following for small cell backhaul. For each case, a reference is made to Requirements from the NGMN's previous macro based 'Optimised backhaul Requirements' document [11]. E.g. RS 1.1 (for small cells) replaces R1 (for macrocells)

7.1 Backhaul Architecture

RS1.1 replaces R1	The NGMN Backhaul solution **SHOULD** allow connecting each small cell BTS to one or also several gateways (e.g. aGW in case of 3GPP LTE standard) for multi-homing purposes, if supported by the used radio standard and implementation. In case of LTE up 16 S1 interfaces MAY be envisioned per e-NB. Typically up to 64000 S1 interfaces per aGW MAY be envisioned.
RS1.2 new req.	In order to provide better scalability and reduced operational effort the small cell BTS network architecture **MAY** include a concentrator node, aggregating small cell BTS' control/user/management plane traffic, e.g. based on the gateway architecture defined by 3GPP for Home NodeB (HNB) and Home eNodeB (HeNB) The aggregation gateway **MUST** offer a 3GPP compliant interface towards the core.
RS1.3 replaces R2	The NGMN Backhaul solution **MUST** allow connecting each e-NB to one or several e-NB's (i.e. X2 interface in 3GPP LTE standard). This list of inter-e-NB connections **MUST** be operator configurable. An auto-discovery mechanism **MAY** be used to reduce the operational effort (the exact protocol and mechanism to be used are for further study). To achieve that, the NGMN Backhaul solution **SHOULD** take advantage of local TNL switching function at any possible point of the NGMN Backhaul solution according to operator decision. Typically up to 128 X2 interfaces **MAY** be envisioned per e-NB. For radio technologies and implementations not supporting inter-BTS connectivity this requirement does not apply.
RS1.4 modifies R55	The NGMN Backhaul solution **MAY** be designed as an open system where each Transport Equipment could be replaced by any Transport Equipment of another supplier and could be managed with the same OSS solution. This excludes eventually the concentrator node mentioned in **RS2**.
RS1.5 replaces R60	The small cell dedicated part of the backhaul network **MUST** offer lower costs per connection than those used for macro cells. This **MAY** be based on usage of cost optimized technology resulting e.g. in slightly lower availability, higher packet loss ratio or higher latency.
RS1.6 same as R3	It **MUST** be possible to build the E2E NGMN small cell backhaul network solution (both base station to aGW and between base stations) using several network elements (e.g. packet microwave, metro optical ring) either in a single or in a multi-administrative area environment.
RS1.7 same as R50	The NGMN Backhaul solution **MUST** be hardware ready to support IPv4/IPv6 dual stack. Software support **SHOULD** be implemented when and where required.
RS1.8 same as R51	The NGMN Backhaul solution **MUST** provide a flexible and scalable way to migrate to full IPv6 environment in the future.
RS1.9 same as R53	The NGMN Backhaul solution **MUST** be compatible with existing and all-IP mobile core networks.

RS1.10 same as R54	It **MUST** be possible to rely on Backhaul segments which are either owned by the Mobile operator or leased from a Third Party.
RS1.11 same as R56	The NGMN Backhaul solution **MUST** use standardized physical and transport protocols as defined by ITU-T, IEEE, IETF, etc. in order to guarantee interoperability in a multi-vendor environment.
RS1.12 same as R57	The Control Plane/Management Plane/Provisioning functions which are used to build the logical connectivity between several e-NB's **MUST** be able to deal with all X2 connections per e-NB Transport Module without any constraint.
RS1.13 same as R58	The Control Plane/Management Plane/Provisioning functions which are used to build the logical connectivity between each base station and aGW **MUST** be able to deal with all the S1 connections per e-NB Transport Module without any constraint.
RS1.14 same as R59	The Control Plane/Management Plane/Provisioning functions which are used to build the logical connectivity between the EPC and each e-NB's **MUST** be able to deal with all the S1 connections per EPC node without any constraint.

7.2 Coverage and Connectivity

RS2.1 new req.	To be considered as within coverage, the small cell backhaul solution **MUST** provide connectivity between a small cell and transport network Point of Presence. Such a connectivity supports the required quality of service in terms of capacity, latency, availability etc.
RS2.2 new req.	The Last mile small cell backhaul solution **SHOULD** provide a high level of coverage to small cell locations below rooftop level e.g. on street furniture or sides of buildings.

7.3 Capacity Provisioning

RS3.1 new req.	When deployed at hotspot locations, the loaded small cell capacity **SHOULD NOT** be limited by the backhaul solution (including control plane, management plane, transport and IPSec overheads). For coverage not-spots, basic connectivity is acceptable.
RS3.2 new req.	For good quality of consumer experience, the peak rate capability of the small cell **SHOULD** also be supported by the backhaul solution.
R3.3 new req.	Capacity required for a number of small cells aggregated by multi-point backhaul **MAY** be: Provisioning=max(peak, N x busy time mean), where the peak and busy time mean vary with the technology choice according to Figure 12 and Figure 13 earlier in this report.
RS3.4 new req.	When provisioning for multiple technologies at a single site, the total provisioning **SHOULD** be the greater of the individual peaks, or the sum of the busy time means.

7.4 QoS Support

RS4.1 modifies R4	The e-NB/aGW Transport Module **MUST** map the radio QoS Class Identifiers (QCI), as well as control plane, synchronisation and management flows to transport QoS markings (L2 or L3 according to operator design choice). The transport QoS markings will then be used by the Transport Equipment to identify the traffic that needs to be carried in each Class of Service (CoS) supported over the Backhaul network. Each transport CoS **MUST** be marked in a different way at transport level (L2 and/or L3 according to operator design choice) to allow traffic to be differentiated in an E2E way.
RS4.2 same as R5	As no unique mapping solution seems visible, mapping between QCI's and transport QoS markings at the e-NB/aGW Transport Module (as per R4) **MUST** be configurable.
RS4.3 same as R6	The Transport Equipment **MUST NOT** modify the QCI-based classification and transport QoS marking done by the e-NB/aGW Transport Modules (i.e. preserve service Class of Service). The Transport Equipment **MAY** add an underlying transport layer with different extra marking but **MUST** maintain the E2E QoS consistency (i.e. when several CoS exist it **MUST NOT** remark as highest priority traffic the traffic that the e-NB/aGW Transport Modules have previously marked as lowest priority traffic).
RS4.4 same as R7	The NGMN Backhaul solution **MUST** be able to support different classes of traffic with different QoS parameters guaranteed. 4 transport CoS **SHOULD** be supported at least. The performance attributes of each CoS are FFS and should be in line with the Standardized QCI characteristics specified by 3GPP in TS 23.203.
RS4.5 same as R8	The NGMN Backhaul solution **SHOULD** provide bandwidth savings by performing packet aggregation at any possible point in the network according to operator decision. This aggregation **MUST** be done in a differentiated way by taking into consideration the different transport marking levels.
RS4.6 same as R9	The NGMN Backhaul solution **SHOULD** support QoS-aware traffic shaping at the e-NB/aGW Transport Modules and at any demarcation point between the mobile operator and a third party transport provider taking into account the E2E delay budget (refer to R48).
RS4.7 same as R10	The Transport Equipment **MUST** support queuing and forwarding using transport priority information. Priority **MUST** be able to be determined based on one or several methods (e.g. IP DSCP, Ethernet pbit). Not all these methods need to be implemented in the Transport Equipment but only the one(s) supported by each underlying transport technology (e.g. no mandatory need to support underlying Ethernet pbit marking if MPLS-based L3VPN is used to backhaul NGMN traffic).
RS4.8 same as R11	The e-NB/aGW Transport module **MUST** forward the traffic to the Transport Equipment in a fair way within the same CoS i.e. making sure that all QCI's included in the same transport CoS will get access to the allocated bandwidth in a Weighted Fair Queuing (WFQ) way.

RS4.9 **modifies R21**	The e-NB/aGW **SHOULD** perform admission control for GBR bearers based, among others, on the availability of transport resources according to the operator specified provisioned bandwidth.
RS4.10 **same as R22**	The e-NB/aGW **SHOULD** perform QoS-aware UL/DL traffic shaping according to the operator specified provisioned bandwidth where: • In the DL the scheduler **SHOULD NOT** schedule more traffic than transport capacity is available in the first mile. • In the UL, when transport resources are not available, the UE scheduling grants **SHOULD** be reduced to avoid sending packets over the air interface that need to be dropped in the transport layer.
RS4.11 **same as R23**	The e-NB and the aGW **SHOULD** perform admission control based on the current availability and performance of transport resources; that is, taking into account the possibility of temporary backhaul bottleneck as opposed to NGMN air interface bottleneck. This mechanism **SHOULD** be applied finding the best trade-off between signalling overhead and network availability information consistency. To achieve this, the NGMN Backhaul solution **MAY** make use of any coordination mechanism between e-NB/aGW Transport Modules and Transport Equipment.
RS4.12 **same as R25**	The NGMN Backhaul Solution **SHOULD** take advantage of any possible exchange between e-NB/aGW and Transport Equipment (e.g. congestion indication, bandwidth reporting), in order to fully optimise the backhaul bandwidth optimisation and QoS performances. For instance a protocol like COPS, Diameter or ANCP MAY be used for bandwidth reporting but the exact mechanism to be used is FFS.
RS4.13 **same as R46**	The NGMN Backhaul solution **MUST** guarantee the E2E SLA's (internal and external service agreements) and provide tools and metrics to monitor the SLA in particular in terms of performance and availability. The complete set of performance attributes are FFS and should be in line with the Standardized QCI characteristics specified by 3GPP in TS 23.203
RS4.14 **same as R47**	Different, flexible SLA's in terms of performance (e.g. Max delay, jitter, Max PLR, Max PER) **SHOULD** be provided to accommodate the needs of different Backhaul segments through the network and e-NB types with a reasonable cost model.
RS4.15 **modifies R48**	The overall backhaul delay budget in one direction from small cell connection point to the core network equipment **SHOULD NOT** exceed 20ms, for 98% packets for high priority Classes of Service or in uncongested conditions. We note that the backhaul latency MUST fit into the operator's overall E2E latency budget for the service(s) being offered.
RS4.16 **same as R49**	Standardized definitions **MUST** be used when defining SLA's (e.g. Ethernet services as per the MEF Mobile Backhaul Implementation Agreement).

7.5 Synchronisation

RS5.1 **same as R36**	In case of centralised *clock* source, the NGMN Backhaul solution **MUST** support clock distribution to the eNodeB for frequency synchronisation and support phase/time alignment (for eNodeBs with TDD mode of operation). Note: Several methods have been considered for synchronisation as a single solution or combined together (the following list is not exclusive): -Physical-based methods (e.g. Synchronous Ethernet) (Note: for frequency only) -Long term stable oscillator (stable for months) (Note: for frequency only) -Protocol-based methods (e.g. NTP, IEEE1588v2) with/without intermediate nodes support (e.g. boundary clock implementation in intermediate backhaul nodes for IEEE 1588v2) -GNSS (e.g. GPS, Galileo, GLONASS, Beidou)
RS5.2 **same as R37**	The e-NB/aGW Transport Modules **SHOULD** support multi clock source input for synchronization, and be able to recover the synchronization from the most accurate source available at any given time according to the synchronisation hierarchy defined for failure protection.
RS5.3 **new req.**	RS41: In case of using a central clock system for synchronization, the backhaul of small cells MUST be able to deliver timing info, such that the synchronisation system for a FDD or TDD small cell **can** meet a minimum frequency accuracy of ±0.1 ppm and ± 1.5 us phase for TDD system.

7.6 Availability and Resiliency

RS6.1 **same as R38**	The operator **MUST** be able to design the E2E NGMN Backhaul solution by reducing the availability figures of one (or several) Backhaul segment(s) to achieve a cost efficient solution.
RS6.2 **same as R39**	It **SHOULD** be possible to perform in-service software upgrades of e-NB/aGW Transport Modules and Transport Equipment.
RS6.3 **same as R40**	The NGMN Backhaul solution **SHOULD** protect against failures of the forwarding control processor to increase reliability (e.g. Non-Stop Forwarding, Non-Stop Routing). Typically this **SHOULD** be required in the aGW Transport Module or in Transport Equipment where a failure would imply service outage for a number of e-NB's according to operator design choice.
RS6.4 **same as R41**	Improved reliability of the NGMN Backhaul solution **MAY** be achieved by taking advantage of Path Protection with Fast Restoration (e.g. RSVP-TE based Fast Reroute as described in IETF RFC 4090).

RS6.5 same as R42	In particular, but not only, for Backhaul segments with high availability requirements, 99.99% service continuity (understood as mobile connectivity continuity) **SHOULD** be the target figure. This means that during 99.99% of the time, the NGMN Backhaul solution will not experience interruptions that would force mobile users to be disconnected and then force them to set up again their service connection. As a reference, the order of magnitude of such allowed interruption time (including radio, backhaul, etc.) is usually in the range of 500ms - 2s for a single outage. Note: the 99.99% service continuity is only related to the NGMN Backhaul solution and does not include discontinuity due to e.g. e-NB itself (e.g. e-NB upgrade) or the radio layer.
RS6.6 same as R43	Operators wanting to guarantee a certain Quality of Experience (QoE) **SHOULD** have the option to define more stringent requirements. This means that the NGMN Backhaul solution will not experience interruptions that would impact QoE of mobile users. As a reference the order of magnitude of such allowed interruption time is within 50ms - 250ms range for real-time services like voice or TV streams.
RS6.7 same as R44	In case the e-NB is connected to more than one aGW's, switching from the primary aGW to the secondary one **SHOULD** be coordinated between e-NB/aGW Transport Module and Transport Equipment to achieve the fastest protection as possible.
RS6.8 same as R45	The protection switching from the primary aGW to the secondary one **SHOULD** be achieved within 50ms - 250ms range.

7.7 Physical Design / Hardware Architecture

RS7.1 modifies R77	The Small Cell backhaul solution **SHOULD** be able to adapt an increasing amount of traffic according to the radio capacity requirements, and that individual interfaces that MUST be chosen in this way with future perspective of LTE to LTE-A (100Mbps /cell to 1Gbps/Cell).
RS7.2 modifies R78	Non-service impacting insertion of new interface cards/ plug-in units **MAY** be supported (e.g. hot insertion without requiring restart).
RS7.3 same as R79	RJ-45 and fibre optic connectors **SHOULD** be the targeted types for tethered or cabled transmission modules in the Small Cell backhaul solution.
RS7.4 modifies R81	Functional integration of the Transport Equipment in the e-NB Transport Module **SHOULD** also be considered (e.g. an all outdoor microwave radio can be integrated with the e-NB for Small Cell Module).
RS7.5 same as R82	The Small Cell backhaul solution **MUST** offer the highest reliability figures that still make sense from an economic perspective.

RS7.6 **modifies R83**	The Small Cell backhaul solution **SHOULD** be highly integrated with a “physical enclosure” or “unit” of the e-NB, by optimising space as far as possible in outdoor deployments.
RS7.7 **same as R84**	The Transport Equipment **SHOULD** share with the e-NB for Small Cell in a collocated site a single power supply and battery backup unit.
RS7.8 **same as R85**	The Small Cell backhaul solution **MUST** be in conformance with all well-known ITU-T/Continental/National standards concerning Power Supply.
RS7.9 **new req.**	When Power over Ethernet technology is used, the Small Cell backhaul solution **MUST** be in conformance with IEEE 802.3at requirements, or other applicable standards.
RS7.10 **same as R86**	The Small Cell backhaul solution **MUST** be designed to achieve reduced power consumption targets on the whole system as well as individual components within the constraints of operational specifications.
RS7.11 **same as R87**	The mean power consumption of the Small Cell backhaul solution **MUST** be as low as possible to comply with environment protection and energy saving.
RS7.12 **same as R88**	The hardware of Small Cell backhaul solution **SHOULD** support several power consumption modes adapted to the current traffic, the environmental conditions, etc. and **SHOULD** automatically switch to the mode with the lowest possible power consumption when possible.
RS7.13 **same as R89**	The Small Cell backhaul solution **MUST** be in conformance with all well-known ITU-T/Continental/National standards concerning EMC, safety, resistibility, climatic, mechanic, and acoustic conditions.
RS7.14 **new req.**	The Small Cell backhaul solution **SHOULD** be designed to protect / avoid from the damage due to lightning strikes and other environmental high voltage current surge.
RS7.15 **new req.**	The pole where the equipment is mounted might sway due to wind or environmental effects. The equipment **SHOULD** be designed to avoid the outage due to the pole sway. If the outage occurs, the equipment must recover the link by itself as soon as possible.

7.8 Security

RS8.1 modifies R61	The network elements in an E2E NGMN Backhaul solution **SHOULD** support an adequate number of security oriented, Industry recognized mechanisms and tools to provide a secure transport of services from a small cells to the core network. If the backhaul network is considered as trusted by the mobile operator, the network elements **SHOULD** provide any suitable mechanisms and algorithm to enable data integrity, authentication and confidentiality of the traffic exchanged.
RS8.2 modifies R62	When a segment of the NGMN Backhaul solution cannot be trusted by the mobile operator (i.e. when secured transport is not implemented as defined in R69) or the small cell is not considered to be physically secured, authentication, encryption and data integrity protection mechanisms **MUST** be implemented.
RS8.3 modifies R63	The e-NB/aGW Transport Module **SHOULD** segregate data, control and management planes to limit the access (e.g. using any available method as L2/L3 VPN, traffic segregation in VLAN, PW or VRF, etc.).
RS8.4 modifies R64	The small cell backhaul solution security **MUST** NOT break any security mechanisms of the small cell itself (e.g. auto-configuration or zero touch approach, as the local storage of certificates). This MUST NOT preclude the implementation of any other solutions where certificates of keys are exchanged dynamically.
RS8.5 modifies R65	The small cell backhaul solution **MUST** support per management system user authentication and controlled access levels in any network element that is part of it.
RS8.6 modifies R66	The small cell backhaul solution **MUST** support the transport of secure access to the small cell by the management system user (e.g. SSH/SCP, SNMPv3, etc.).
RS8.7 modifies R67	The small cell backhaul solution **MUST** support protocols security on behalf of a small cell (e.g. but not limited to per peer queuing for protocols, protocol security with SHA-256 and TCP authentication).
RS8.8 modifies R68	The small cell backhaul solution **MUST** support network element CPU Overload Control.
RS8.9 modifies R69	In case of non-trusted NGMN Backhaul solution, communication between a small cell and a SeGW and/or management node **MUST** be mutually authenticated and integrity and confidentiality protected.
RS8.10 modifies R70	In case a small cell is connected to a non-trusted backhaul, segment communication between the same small cell and other network entities within a trusted domain segment **MUST** go through a SeGW connecting the untrusted backhaul segment with the trusted backhaul segment. Communication between the small cell and SeGW SHOULD be mutually authenticated and integrity and confidentiality protected

RS8.11 **modifies R71**	In case a small cell is connected to a non-trusted backhaul, segment communication between the same small cell and other network entities within a trusted domain segment **MUST** go through a SeGW connecting the untrusted backhaul segment with the trusted backhaul segment. Communication between the small cell and SeGW **SHOULD** be mutually authenticated and integrity and confidentiality protected
RS8.12 **same as R72**	The small cell backhaul solution **MUST** support line rate traffic filters (Layer 2 - Layer 4).
RS8.13 **same as R73**	The NGMN Backhaul solution **MAY** support traffic monitoring/mirroring capabilities.
RS8.14 **same as R74**	The Transport Equipment **MUST** assure secure exchange of control protocols (e.g. Transport Equipment routing/signalling). This **MAY** be achieved e.g. using authentication or choosing a non-IP encapsulated routing protocol
RS8.15 **same as R75**	The small cell backhaul solution **MUST** provide the ability to support single sign-on for administrator level privileges.
RS8.16 **modifies R76**	A secure mechanism to protect OAM traffic (from a small cell and internal to the backhaul network) by operation personnel intervention **MUST** always be available even if the small cell backhaul solution is considered trusted by the operator.

7.9 Operational, Management, Traffic Engineering

RS9.1 **modifies R26**	The NGMN Backhaul solution **MUST** provide in a multi-vendor environment powerful/ efficient management and traffic engineering tools to reduce OPEX thanks to: -E2E Service level management - E2E Integrated Element/Network/Service management - Automation for E2E network and service creation/tear down - Minimal on-site configuration during equipment deployment
RS9.2 **new req.**	The NGMN Backhaul solution **SHOULD** enable plug&play installation of small cells, via remote configuration and provisioning or pre-configured RAN and transport equipment at the cell-site. This **SHOULD** also be possible when multiple access technologies are supported in the same cell.
RS9.3 **same as R27**	The NGMN Backhaul solution **MUST** support standard MIB's.
RS9.4 **same as R28**	The NGMN Backhaul solution **MUST** support a logical northbound interface for integration into other OSS packages. Northbound Configuration Management **MUST** address the configuration of the e-NB/aGW Transport Modules. No specific requirements are foreseen for this interface.

RS9.5 **same as R29**	The Transport Equipment **SHOULD** support a logical southbound interface for integrating any third-party Transport Equipment, e-NB/aGW Transport Module or NMS software into the OSS solution. No specific requirements are foreseen for this interface.
RS9.6 **same as R30**	The NGMN Backhaul solution **MUST** be able to pro-actively, passively and on-demand monitor the OAM capabilities of the underlying network elements. Note: • "Pro-active monitoring": monitoring that is persistent and meant to identify events before or as they occur. Generally this method introduces extra traffic in the network. • "Passive monitoring": monitoring that does not result in extra traffic in the network. Typically this is achieved with counters and other internal node intelligence; where alarms are triggered when thresholds are crossed. • "On-demand monitoring": monitoring initiated for a limited duration for short term measurements and diagnostic purposes.
RS9.7 **same as R31**	The NGMN Backhaul solution **MUST** support mechanisms for logging events (e.g. Syslog).
RS9.8 **same as R32**	The NGMN Backhaul solution **MUST** support OAM in a multi-vendor environment by simplifying network operations with reactive and proactive OAM tools like: •Automatic notifications of alarms (some alarm types **MUST** be flexibly filtered according to operator's specific configuration) • Per segment, per administrative area and E2E Connectivity Check • Per segment, per administrative area and E2E Troubleshooting (e.g. Traceroute tool to know the exact functional path of a connection)
RS9.9 **same as R33**	The NGMN Backhaul solution **MUST** be transparent to OAM flows of the RNL.
RS9.10 **new req.**	The small cell base station's transport interface **SHOULD** support OAM mechanisms as described in **RS69 (R30), RS70 (R32).** If no equipment at the cell-site can support such functions, then the base station's transport interface **MUST** support these features.
RS9.11 **new req.**	In the case when multiple access technologies are present in a single site, the small cell backhaul solution **MUST** notify automatically of the failure of one of them and identify the failing access element
RS9.12 **modifies R34**	The small cell backhaul solution **SHOULD** provide E2E or per segment QoS Performance monitoring (e.g. Delay, Jitter, PLR, PER) based on standard mechanisms such as ITU-T Y.1731, Y.1564 or IPPM TWAMP (RFC 5357), OWAMP (RFC4656) and related RFCs. These functions **MAY** also be supported by the base station's transport interface.