

Backhaul Provisioning for LTE-Advanced & Small Cells

by NGMN Alliance

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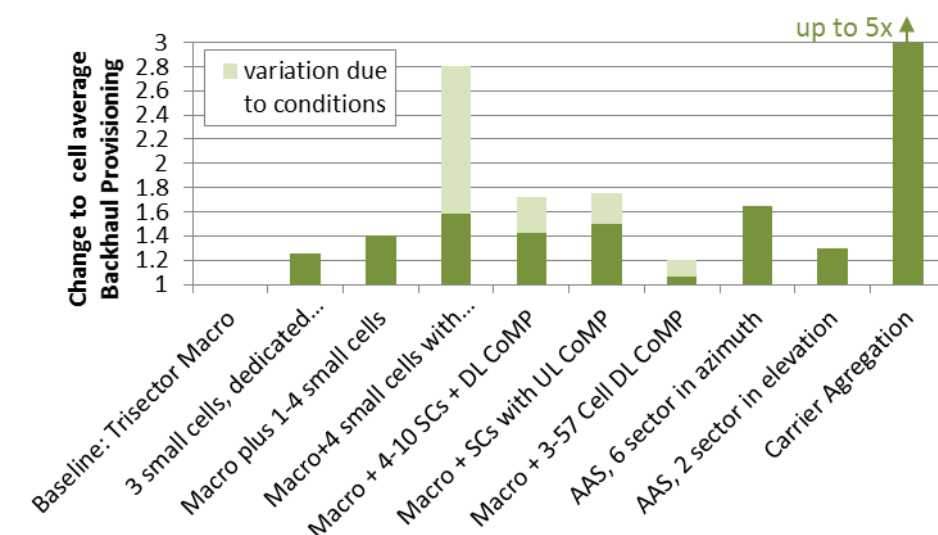
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Executive Summary

This paper considers transport capacity provisioning in LTE-Advanced (release 10) heterogeneous networks. It builds on the detailed analyses in LTE release 8 homogenous macrocells networks presented in NGMN's "Guidelines for LTE Backhaul Traffic Estimation" [13], and also in "Small Cell Backhaul Requirements" [14]. These works showed that backhaul traffic per cell site can be characterised by a 'busy time' loaded figure and a 'quiet time' peak. Perhaps counter-intuitively, the highest data rates seen on a last mile backhaul link occur during the light loading conditions needed to achieve the 'headline' peak user data rates. When the whole network is busy, inter-cell interference and users with a range of signal qualities result in lower cell average throughput figures. For the LTE downlink, peak rates are around 4-6x the busy time mean. When provisioning transport for the 'last mile' to the base station, the peak can dominate. When provisioning for aggregates of several cells towards the core network, the busy time mean dominates.

There is no one feature set representing LTE-Advanced, rather a number of techniques which each apply in different situations: For the super-macro site where space is available, LTE-Advanced enables additional MIMO antennas, increasing both cell average capacity and peak rates. Where additional spectrum is available, carrier aggregation enables this to be efficiently accessed. Where operators have very limited space to deploy equipment, LTE-Advanced facilitates network densification with small cells, adding eICIC to co-ordinate interference between macro and small cells sharing the same spectrum. For operators with access to low cost fibre transport, Centralised or Cloud-RAN architectures with CoMP (Co-ordinated Multi-Point) can exploit interference between cells to enhance data rates for users at the cell edge.

We find that with LTE-Advanced, it is not so much the feature itself which provides the benefit, but the increases in spectrum, site density and MIMO antennas that the features enable. When evaluating backhaul capacity, it is the site configuration in terms of antennas, cells per site and total MHz of spectrum which dominate the calculation. LTE-Advanced features then typically increase cell average capacity between 30 and 75% compared to a similar configuration with LTE release 8, as shown in the figure below. In some cases, the benefits varied depending on the assumed deployment conditions, as shown.



We consider also overheads added to user data in order to transport it from base station to core network in a secure manner. Since overheads are fixed in size, the relative proportion depends on the packet sizes of user plane data. A high level analysis shows that a traffic mix with voice and video results in a higher proportion of smaller packets than would be the case where file transfer is more dominant. Overheads ranged from 11-30% in our example traffic mixes. These overheads apply equally to LTE release 8 and LTE-Advanced.

Contents

1.	Introduction	4
2.	Baseline Release 8 User Plane Backhaul Traffic Characteristics	5
3.	Impact of LTE-Advanced features on User-Plane backhaul traffic	7
3.1.	Sectorisation	7
3.2.	Small Cells, Het nets and eICIC	8
3.3.	CoMP	9
3.3.1.	Downlink CoMP	9
3.3.2.	Uplink CoMP	11
3.3.3.	Summary of CoMP Gains	11
3.4.	Carrier Aggregation	12
3.5.	LTE-Advanced MIMO	13
3.6.	Summary of impact of LTE-Advanced Features on backhaul capacity	14
3.6.1.	Cell Average Throughputs	14
3.6.2.	Peak rates and backhaul provisioning	15
4.	Single eNodeB Transport Provisioning	16
4.1.	Components of Backhaul Traffic	16
4.1.1.	X2 Traffic	16
4.1.2.	Control Plane, OAM and Synchronisation Signalling	16
4.1.3.	Transport Protocol Overhead	16
4.1.4.	IPsec	17
4.1.5.	Impact of traffic mix and packet size distribution on overheads	17
5.	Conclusions	18
6.	References	19

1. Introduction

The performance of cellular network technologies is continuously evolving to keep pace with increasing consumer demand for mobile broadband. Next generation mobile networks offer both increased capacity to shift *more* data, as well as high rates to provide *better* experiences for users.

Increased broadband performance requires enhancements to consumer devices, to base stations and of course the backhaul that connects base stations to the core network and internet beyond, as illustrated in Figure 1. This document considers the capacity requirements for backhaul networks serving next generation mobile networks.

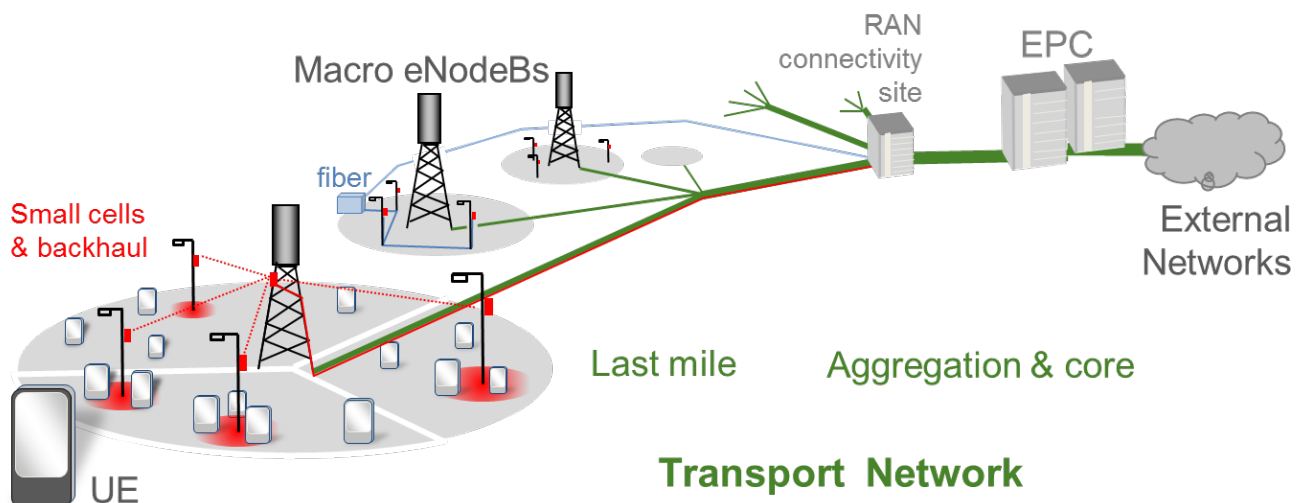


Figure 1: The Heterogeneous Radio Access Network and Supporting Transport Connectivity

The NGMN has already published two sets of backhaul guidelines, illustrated in Figure 2. [13] develops a model for the transport capacity needed to support LTE release 8 macrocells, and [14] extends this to release 8 small cells deployed in a dedicated carrier. In this document, we look at the new co-ordination features and heterogeneous network topologies enabled by LTE-Advanced and consider the impact on capacity requirements for the supporting backhaul network. We analyse both the user plane traffic as well as the overheads needed for transport.

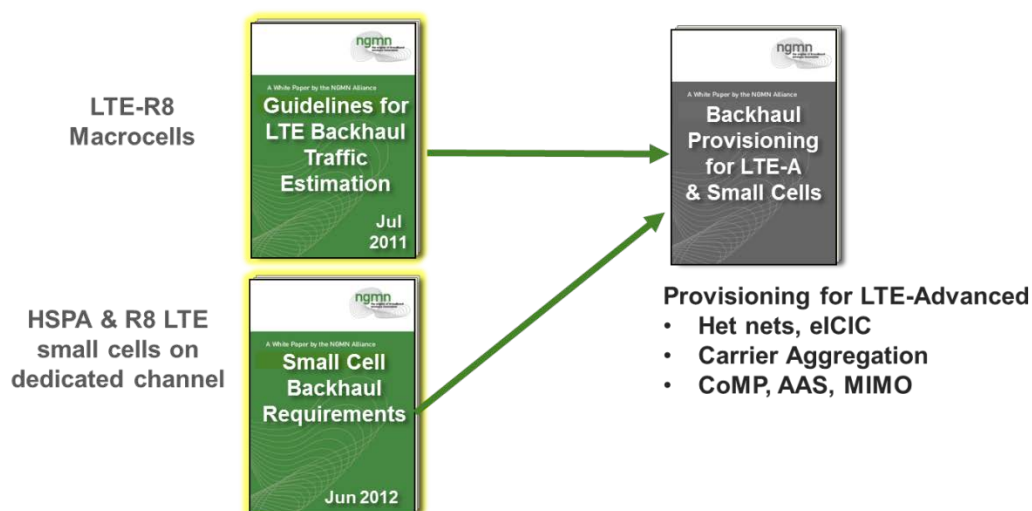


Figure 2 Existing NGMN publications on Backhaul Capacity and role of this paper

2. Baseline Release 8 User Plane Backhaul Traffic Characteristics

Figure 3 illustrates the variation in cell average spectral efficiency during busy and quiet times in the network. During busy times (Figure 3a), there are many UEs being served by each cell. The UEs have a range of spectrum efficiencies, depending on the quality of their radio links to the eNodeB. Since there are many UEs, it is unlikely that they will all be good or all be bad, so the cell average spectral efficiency (and hence cell throughput) will be somewhere in the middle.

During quiet times however, there may only be one UE served by the cell at a given instant. The cell spectrum efficiency (and throughput) will depend entirely on that of the served UE, and there may be significant variations. Figure 3 (b) shows the scenario under which the highest UE and cell throughputs occur: A single UE with a good link has the entire cell's spectrum to itself. This is the condition which represents the “headline” figures for peak data rate. Peak download rates of 150Mbps have been demonstrated for LTE Rel. 8 with 20MHz bandwidth (and 2x2 MIMO) [3], and peak rates beyond 1Gbps are possible with LTE-Advanced.

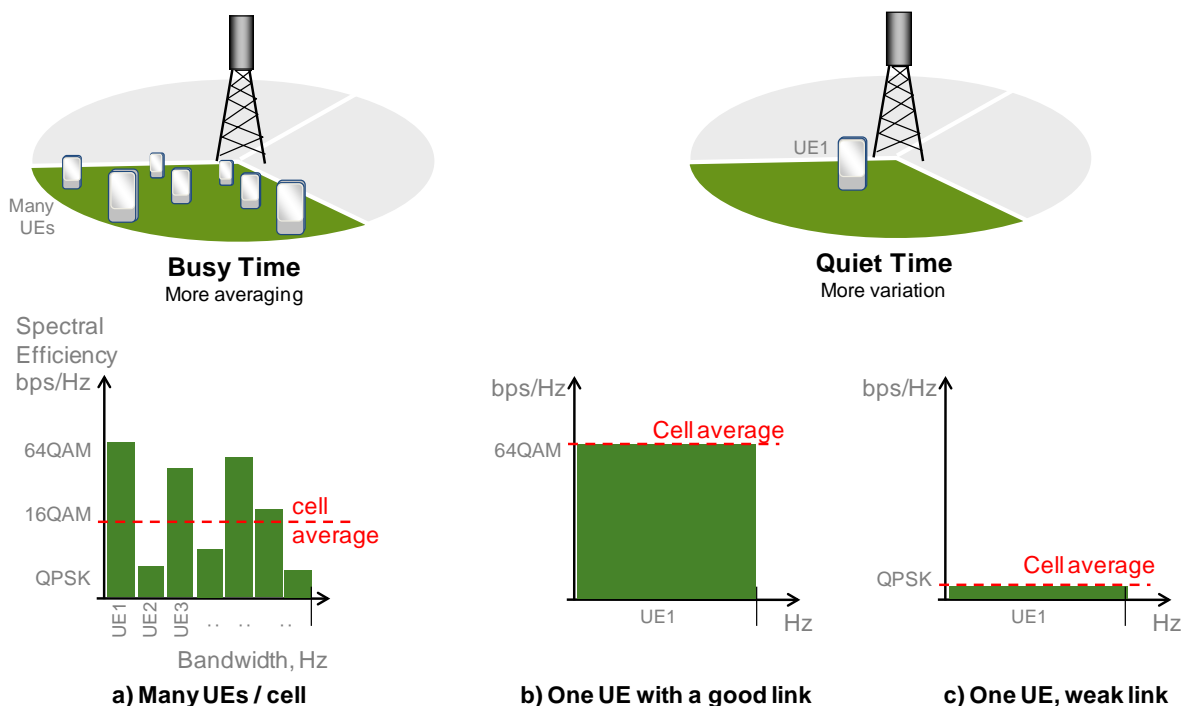


Figure 3 Why peak cell throughput occurs during quiet times

NGMN simulations have been used to evaluate cell average throughputs for LTE macro networks for both busy and quiet time peaks, as shown in Figure 4, from [13]. Additional results for HSPA and small cell environments are shown in Figure 5, from [14].

In the macro cell case we consider the peak as the 95%-ile user throughputs from our simulations. In the small cell case, peaks are expected to be more prevalent and so we use the device capability and channel bandwidth to determine the peak rate.

In the remainder of this paper, we consider how LTE-Advanced features will change these baseline figures, and thus increase the amount of backhaul capacity to be provisioned.

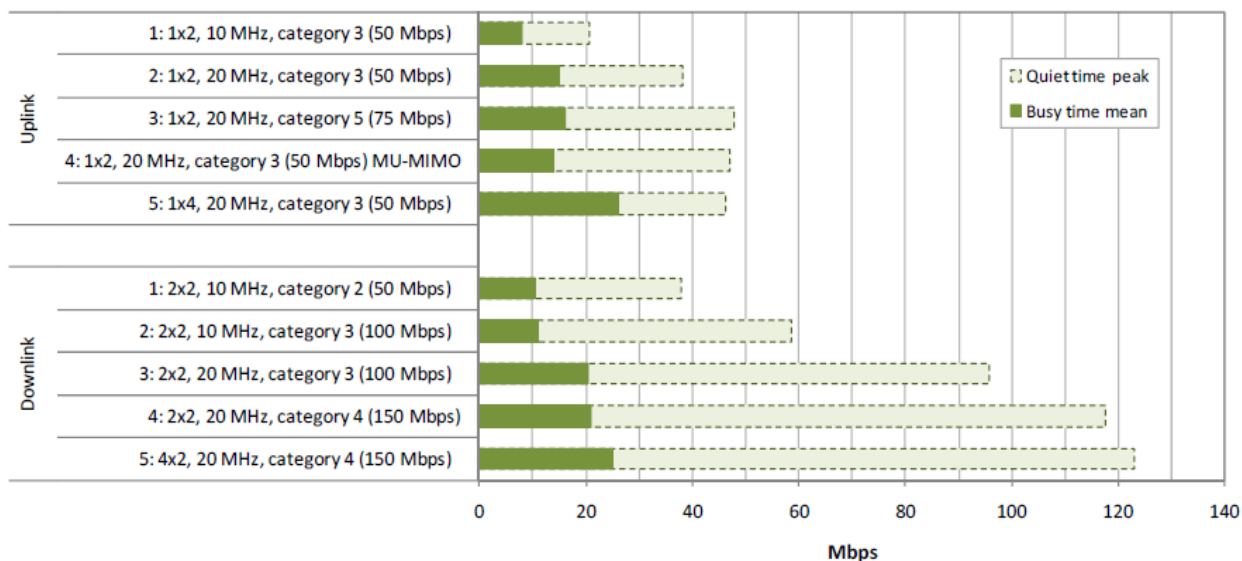


Figure 4 Baseline user plane cell throughputs for various LTE rel. 8 tri-sectored macrocell configurations [13]

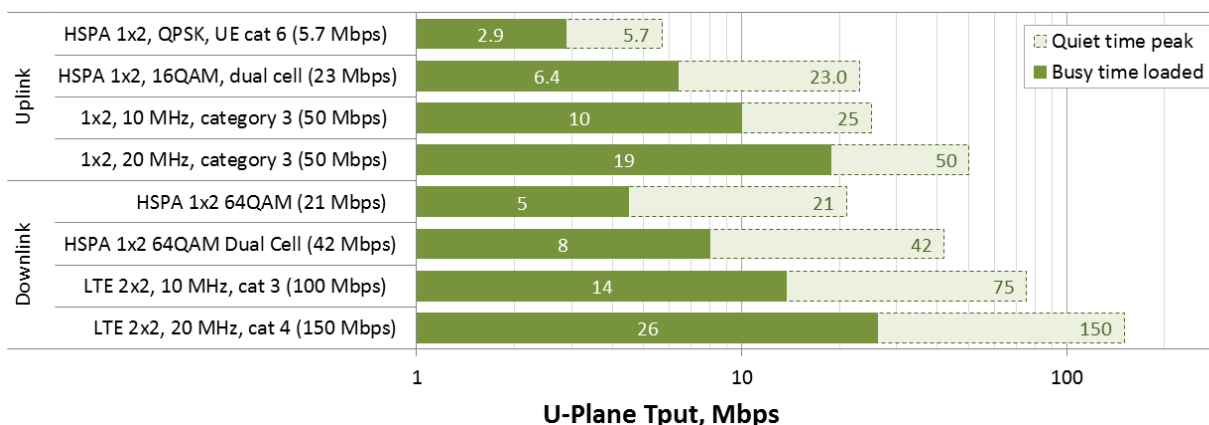


Figure 5 Baseline user plane cell throughput for HSPA and LTE rel. 8 Small Cells in dedicated carriers [14]

3. Impact of LTE-Advanced features on User-Plane backhaul traffic

Here we consider the different features introduced in LTE advanced and their impact on loaded and peak cell throughputs. Techniques are focussed on improving cell edge user performance are not discussed here as this does not impact backhaul capacity provisioning.

Benefit figures given in the following sections are based on the views of operators and vendors within the NGMN augmented with figures drawn from the open literature. In some cases we see variations in the benefit of a technique depending on the deployment scenario assumed. Where possible we describe the causes of these variations. It should be noted however, that the figures are given to assist operators in understanding the impact to backhaul capacity. They do not constitute requirements for the LTE-advanced features themselves.

3.1. Sectorisation

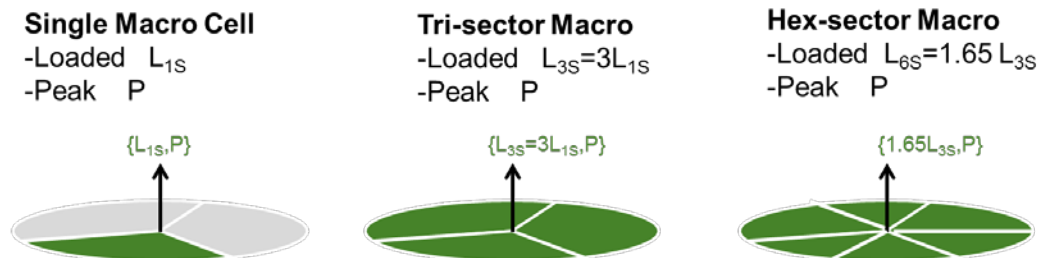


Figure 6 Impact of sectorisation on user plane cell throughputs

Baseline cell macrocell throughput results were based on cells within tri-sectored network, so by definition have a third that of a tri-sectored macro site. Further sectorisation increases capacity but has diminishing returns. We further note that:

- Larger antenna apertures are needed to maintain cell overlap with more sectors
- Angle spread in the environment impacts sectorisation gains.

For hex sectoring in a typical macrocell environment we see 1.65x loaded cell throughput of a tri-cell site based on a range of inputs from our members.

Sectorisation in the elevation plane is also possible, benefits of this are generally less than with horizontal sectorisation as the user are more typically distributed widely in the horizontal plane than in elevation. However, there are scenarios where elevation sectorisation is suitable as discussed in [17]. As a general guideline, we find two elevation sectors provides around 1.3x the capacity as a single elevation sector.

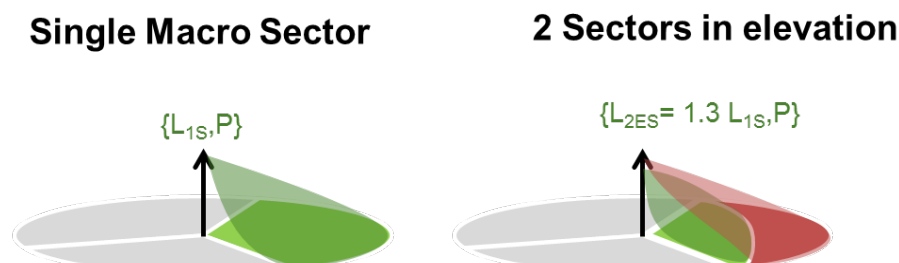
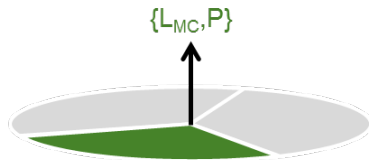


Figure 7 Impact of sectorisation on user plane cell throughputs

3.2. Small Cells, Het nets and eICIC

Single Macro cell



Small Cell, Dedicated Carrier

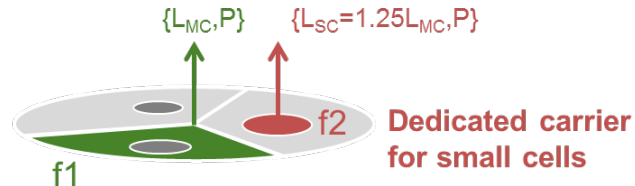
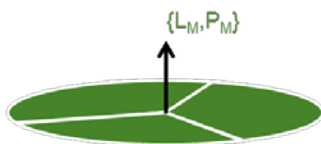


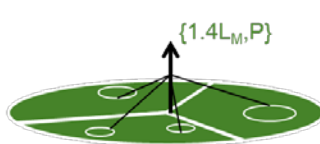
Figure 8 Comparison of Small cell Macro cell throughputs – dedicated carrier

Small cells in a dedicated channel achieve a higher spectral efficiency than a macro cell due to improved SINR conditions: Users tend to be clustered around a hotspot, rather than being uniformly distributed, resulting in fewer users in cell edge areas. Small cells tend also to be located down at street level, 'in the clutter' which helps increase isolation from adjacent cell interference. ITU requirements indicate these mechanisms result in a 25% increase in cell average spectral efficiency [14]. Quiet time peaks are expected to be more prevalent in small cell networks than in macro cell networks due to fewer users per cell and increase likelihood of excellent propagation conditions.

Single Macro cell



1-4 Small Cells per macro, Shared Carrier



1-4 Small Cells per macro, Shared Carrier, eICIC

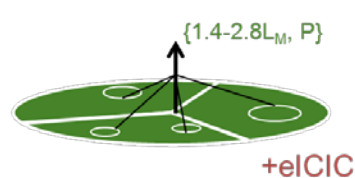


Figure 9 Small and macro cell throughputs with a shared carrier and eICIC co-ordination

The benefit of adding small cells to the macro varies with the deployment conditions. Different member results have shown 1.4x capacity from adding a single small cell – or the same figure from adding 4 small cells. The benefit of eICIC is also variable: Some results show benefits of up to 2x the non eICIC case, whereas others show eICIC can actually degrade overall capacity if conditions are not suitable.

3.3. CoMP

CoMP stands for Co-ordinated Multi Point, where signals can be transmitted from (or received at) multiple cells simultaneously to improve performance. The NGMN have performed a detailed analysis of CoMP schemes in their paper "*RAN Evolution: CoMP Evaluation and Enhancement*", [16]

3.3.1. Downlink CoMP

The increase in cell average throughput - and thus busy time backhaul provisioning - due to downlink CoMP is shown in Figure 10 for a number of macrocell based scenarios. Benefits increase with the size of the co-ordination group, ranging from 7% with 3 cells to 20% with 57 cells. The type of traffic model was also found to impact results, with slightly higher gains observed when using a combined traffic model.

One of the main benefits of CoMP is the benefits to cell edge user throughput. However, they are not included here as they have little or no impact to transport provisioning.

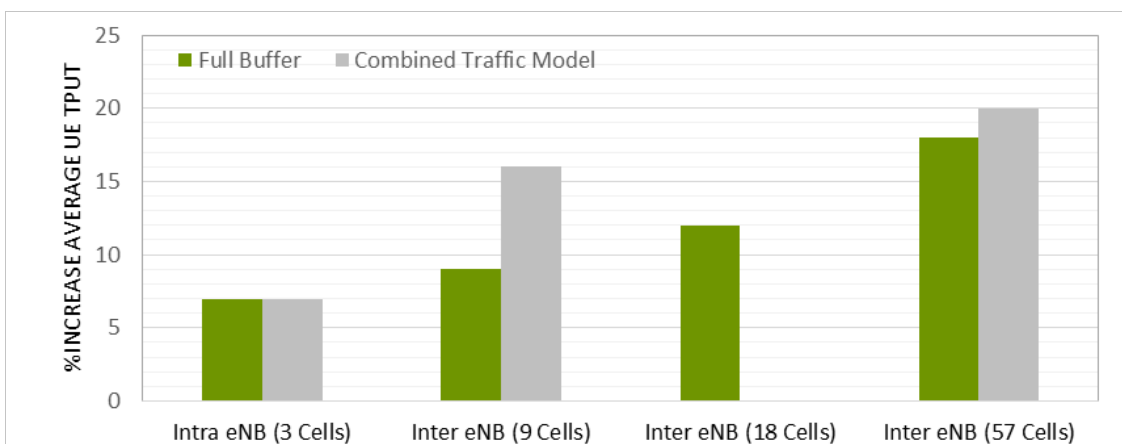


Figure 10 Downlink CoMP Gain in Realistic Environment. Source NGMN [16]

Further results from the 3GPP in Figure 11 indicate CoMP gains in heterogeneous networks and the impact of backhaul latency on these gains. These are based on the scenarios shown in Figure 12. We note that these results are based on Average User Perceived Throughput (UPT) and so should be considered as indicative rather than analogous to the cell average throughput of interest to backhaul planners.

The values presented in Figure 11 represent the median of a number of inputs from different vendors. For example, SCE2a 5ms has median benefit of 22.9% to mean user throughput – but other vendor contributions ranged from 0 to 28 %.

For heterogeneous networks at a density of 4 small cells per macro, CoMP has a small impact on mean user perceived throughput of around 6%. With a denser deployment of 10 small cells per cluster we see up to 23% increase in the dedicated small cell carrier case – indicating the benefit is achieved through co-ordination between only small cells. These increases are only seen for backhaul with 5ms latency. With 50ms latency, CoMP has no benefit to mean UPT. Another source of simulations [18] corroborates with the lower end of these results, showing mean cell throughput increasing by around 5% in both homogeneous and heterogeneous networks with CS/CB CoMP.

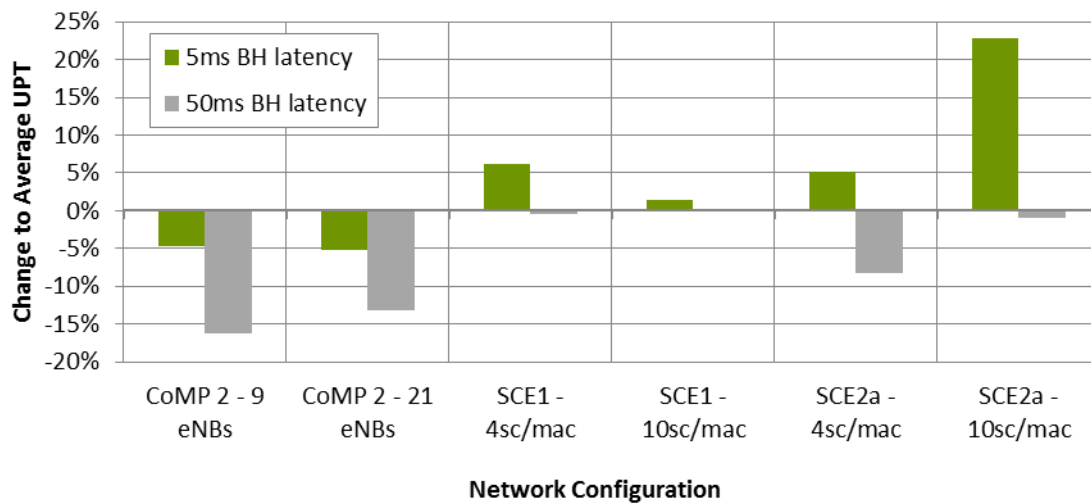
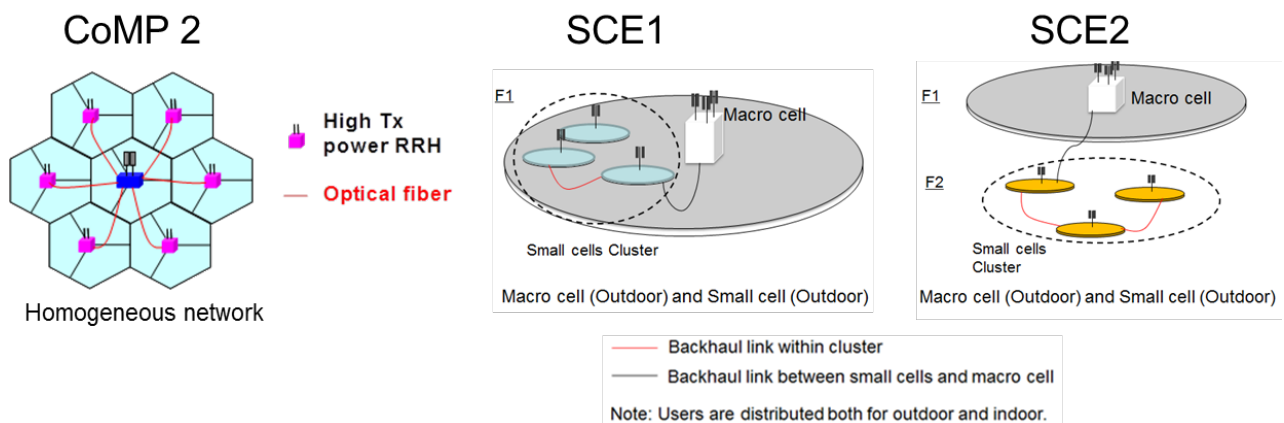


Figure 11 Downlink CoMP Gains over Non Ideal Backhaul (FDD and TDD), Source Data: 3GPP TR 36.874 V12.0.0 §7: Conclusions



- CoMP 2: CoMP operation between **macro eNBs in homogeneous** network with ISD = 500m
- SCE1: CoMP operation between **macro eNB and small cell eNBs** in heterogeneous network, where small cells and macro share the same carrier
- SCE2: CoMP operation between **only small cell eNBs** in heterogeneous network where small cells operate on a dedicated carrier.

Figure 12 Scenarios for CoMP Gains. Sources 3GPP TRs 36.819, 36.872

3.3.2. Uplink CoMP

For a homogeneous macro cell NW, Joint Reception CoMP (JR) has been found to increase cell average throughput by up to 32% in a 3 cell cluster, or 50% in a 9 cell cluster.

In Heterogeneous networks, several trade-offs on the cooperation area have been investigated in [16]. A good performance/complexity trade-off is achieved by limiting the cooperation area to the macro cell coverage. Furthermore, it is also shown that activating CoMP only for UE connected to macro might be an acceptable compromise. This has the advantage of using of conventional (non CoMP) pico BS, and no CoMP overhead on the backhaul. Figure 13 shows these different configurations.

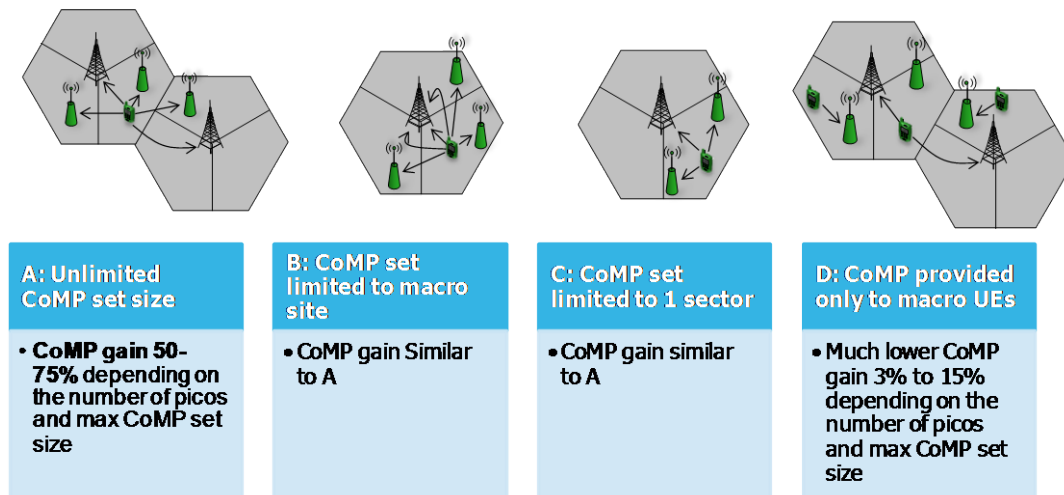


Figure 13 Uplink CoMP Benefit to mean user throughput in various het net configurations (full buffer traffic)

With a non-full buffer traffic model. Higher CoMP benefits can be seen as shown in Figure 14. Increases in cell average throughput range from 12% up to 280% depending on the load and number of receive antennas at the eNodeB.

	2RX antennas		4 RX antennas	
	CE edge	Cell avg	Cell Edge	Cell Average
High load	380	280	160	170
Medium load	180	130	140	12

Figure 14 Uplink throughput increases in % with JR CoMP and non-full buffer traffic for HetNets

Key assumptions and simulation parameters are based on 3GPP 36.814. Additional assumptions are:

- Hotspot scenario "4b", with 1 pico-cell per macro
- Cross-polarized antennas, 2Rx in pico-BS, 2 or 4Rx in macros
- File size 0.5MByte (4Mbit), 8sec upload max. duration (min. throughput requirement 500kBit/s)

3.3.3. Summary of CoMP Gains

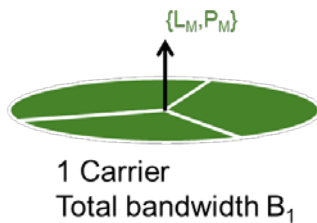
DL CoMP Works best with 5ms or lower backhaul latency. For homogeneous macrocell network, cell average provisioning would need to increase by between 7-20%, depending on the size of the co-ordination group. 3GPP results indicate similar increases in heterogeneous networks might be expected with around 6%-23% increases in UPT observed for 4 – 10 small cells per macro.

UL CoMP Gains of up to 50% are seen for CoMP over a 9 macrocell cluster in a homogenous network. In a heterogeneous network, 50-75% increases in cell average throughput are expected when Joint reception CoMP is applied between small cells and macro with 'full buffer' type traffic. Higher gains of up to 280% are seen with an FTP type traffic model.

3.4. Carrier Aggregation

Carrier aggregation enables operators to combine multiple component carriers, potentially across different bands, to increase the bandwidth available for LTE-Advanced systems. A number of different deployment scenarios and configurations are presented in [19].

Macro cell, single carrier



multiple aggregated carriers

- Loaded rate scales with total bandwidth
- Peak scales too, but limited by device capability

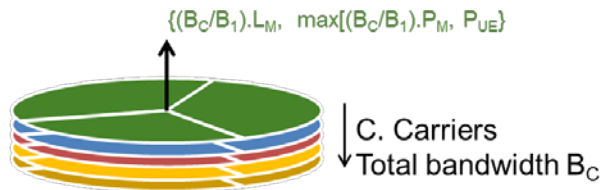


Figure 15 Carrier aggregation backhaul model – linear scaling of peak and cell average rates.

In a simple carrier aggregation configuration, UEs and eNodeBs transmit over multiple carriers to increase both site capacity and peak user data rates. For backhaul provisioning purposes, we assume that the cell average capacity and peak rates are proportional to the total aggregated bandwidth, as illustrated in Figure 15. We note that peak rates may be limited by the device capability.

3.5. LTE-Advanced MIMO

LTE-Advanced provides enhancements to the MIMO schemes available in release 8 as well as increasing the number of antennas that can be combined. A detailed description can be found in [17]. Figure 16 and Figure 17 show the increase in cell average throughput of a range of LTE-Advanced MIMO schemes, relative to the release 8 baseline.

Enhanced MIMO processing from LTE-Advanced (rel 10) increases cell capacity over rel8 by 1.3-1.5 x for a given antenna configuration. 8x2 gives up to 2x cell capacity over 4x2 schemes. LTE-Advanced MIMO gains are shown to be higher in macro cell environments compared to microcells (small cells).

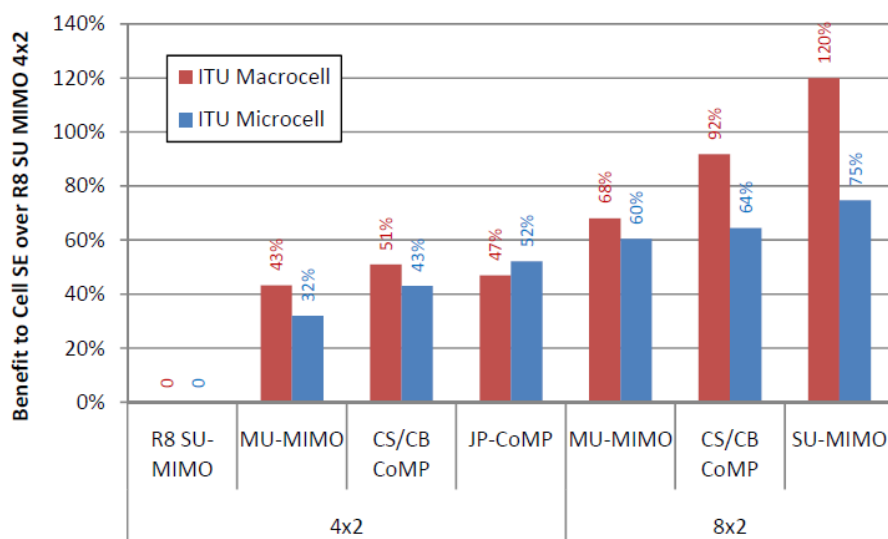


Figure 16 Increase in Cell average throughputs with various LTE-Advanced MIMO schemes, relative to LTE Rel. 8 4x2. Source Real Wireless [15].

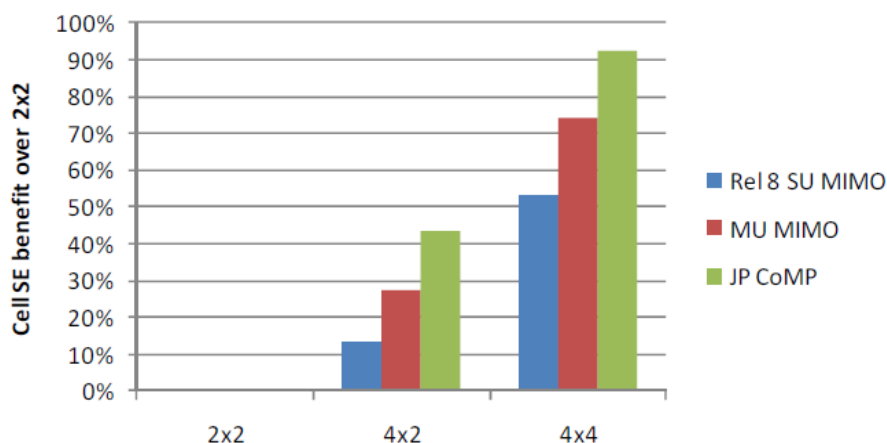


Figure 17 increase in Cell average throughputs for higher order MIMO relative to 2x2. Source Real Wireless [15]

3.6. Summary of impact of LTE-Advanced Features on backhaul capacity

3.6.1. Cell Average Throughputs

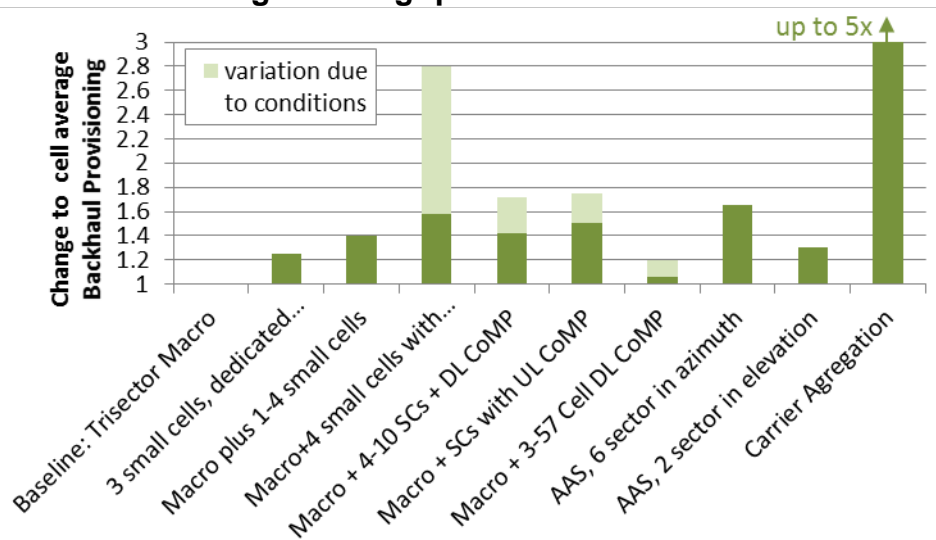


Figure 18 Impact of different cell types, het net configurations and co-ordination techniques on backhaul capacity provisioning for the cell average user plane throughput.

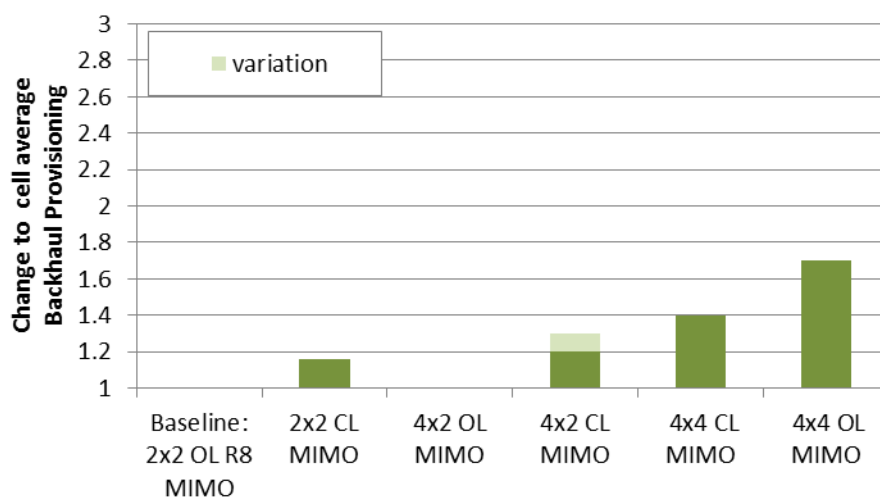


Figure 19 Relative cell average throughput with different MIMO configurations

Figure 18 and Figure 19 summarise the impact of various LTE-Advanced and het net features on the cell average throughput. The light green bars indicate that a range of different data points were received and the increase in throughput depends on the deployment conditions. Figures are normalised to baseline of a single release 8 tri-sector macro site within a larger network of the same.

We note that some of these features also bring benefits to cell edge users, although these are not considered here as they do not impact backhaul provisioning.

Overall we see most LTE-Advanced features increasing cell average user plane backhaul capacity provisioning in the range of 30-75%, with two exceptions, eICIC and carrier aggregation.

In the case of eICIC applied to a het net, we saw a wide range of benefits depending on the how the small cells were deployed. The greatest gains for co-ordination/range extension were seen when small cell locations were not well matched to the demand hotspots. In the case of carrier aggregation, doubling or tripling the MHz spectrum used by a site will - to a first order – double the cell average throughput and peak rates, devices permitting.

3.6.2. Peak rates and backhaul provisioning

The peak throughputs for individual cells can generally be ignored when evaluating backhaul capacity for links carrying aggregated traffic of many cells for two reasons:

- 1) Peak rates require ideal conditions and statistically unlikely to occur simultaneously in multiple cells.
- 2) When a peak does occur in a one cell, it requires little or no interference from adjacent cells, meaning they cannot also be peaking at the same time.

When using transport links dedicated to a single cell, the peak should be taken into account. Earlier, Figure 4 and Figure 5 showed peaks can be 5-6x the cell average rate for a range of LTE release 8 macro and small cell configurations. This has two implications

- a) Point to Point links dedicated to a single site should provision for a peak of 5-6x the average carried traffic
- b) Point to multipoint or links carrying aggregates of more than 5-6 cells can be provisioned for the sum of the cell average throughputs and the peaks will be accommodated.

Our analysis of the impact of LTE-Advanced features on peak rates found:

- **Some features have no impact to peak rates:**
 - Small cells may increase prevalence of peaks, but not the actual rate.
 - CoMP, Sectorisation, MIMO schemes that do not increase spatial multiplexing order (rank).
- **Peak rates increased with the following features:**
 - Carrier aggregation – where device limits permit
 - Higher order MIMO where number of spatial layers is increased

4. Single eNodeB Transport Provisioning

4.1. Components of Backhaul Traffic

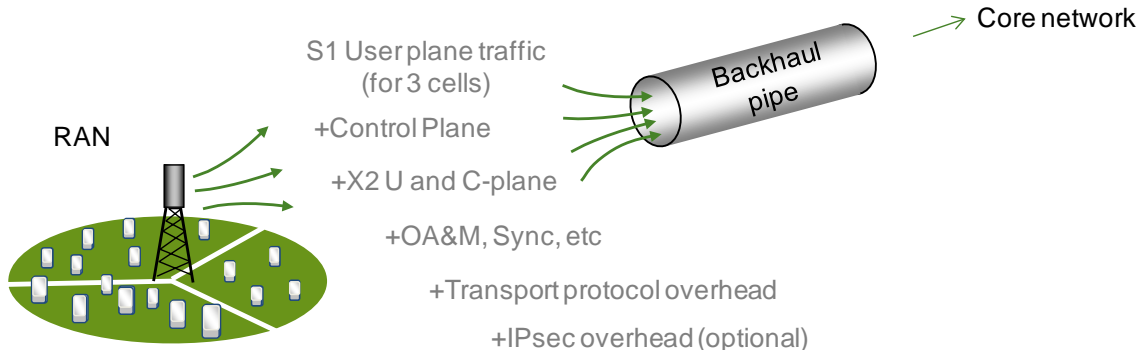


Figure 20 Components of Backhaul Traffic

Backhaul traffic comprises a number of components in addition to the user plane traffic as illustrated in Figure 20. The optimised backhaul group agreed on the following assumptions:

4.1.1. X2 Traffic

The new X2 interface between eNodeBs is predominantly user traffic forwarded during UE handover between eNodeBs. Further analysis of X2 functionality and traffic requirements can be found in [12]. The volume of X2 traffic is often expressed relative to the volume of S1 traffic, with equipment vendors stating figures of 1.6% [9], 3% [10] and 5% [11]. It was agreed to use 4% as a cautious average of these figures. X2 traffic only applies to the mean busy time, as the 'peak' cell throughput figure can only occur when there is one UE in good signal conditions – away from where a handover may occur.

It should be noted that the actual volume of traffic depends on the amount of handover, so cells on motorways for example would see a higher proportion of X2 traffic than an eNodeB covering an office. It was suggested that an X2 overhead around 10% is appropriate for sites serving highly mobile users. Reference [11] also describes the 'batch handover' scenario, where multiple UEs on a bus or train handover simultaneously, temporarily causing high levels of X2.

Some LTE-Advanced schemes require additional signalling over the X2 interface in order to co-ordinate transmissions of neighbour cells. With eICIC, updates to ABS (Almost Blank Sub-frame) patterns would not need to occur very frequently, of order 1 second or more, so the X2 overhead is assumed to be negligible. CoMP schemes do require frequent signalling between base stations, but are generally assumed to require 'ideal' backhaul or front-haul deployments. Details of CoMP signalling overheads can be found in [16].

4.1.2. Control Plane, OAM and Synchronisation Signalling

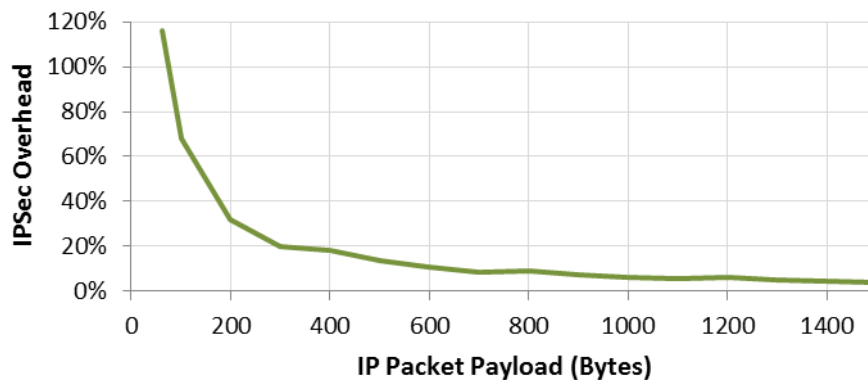
Control Plane Signalling on both S1 (eNodeB to Core) and X2 (eNodeB to eNodeB) is considered to be negligible in comparison to associated user plane traffic, and can be ignored. The same is true for OAM (Operations, Administration and Maintenance) and synchronisation signalling.

4.1.3. Transport Protocol Overhead

Backhaul traffic is carried through the Evolved Packet Core in 'tunnels', which enable the UE to maintain the same IP address as it moves between eNodeBs and gateways. LTE uses either GTP (GPRS tunnelling protocol), which is also used in GSM and UMTS cores, or Mobile IP tunnels. The relative size of the tunnel overhead depends on the end user's packet size distribution. Smaller packets (like VoIP) incur larger overheads. The NGMN backhaul group has assumed an overhead of 10% represents the general case.

4.1.4. IPsec

User plane data on the S1-U interface between the eNodeB and Serving Gateway is not secure, and could be exposed if the transport network is not physically protected. In cases where the operator owns and trusts their transport network, and additional security is not needed. However, if user traffic were to traverse a third party 'untrusted' network, then it should be protected. In such situations, 3GPP specify IPsec Encapsulated Security Payload (ESP) in tunnel mode should be used. Unfortunately this adds a header of around 60 bytes (configuration dependent), which Figure 21 shows can be comparable in size to the payload itself for small packets like VoIP. For larger 1500Byte packets associated with file transfer, the overhead is 4% of the payload. This shows that the net overhead of IPsec depends then on the mix of traffic types being transported and the resulting packet size distribution.



IPsec assumptions: Tunnel mode, UDP Encapsulation, AES-128, esp-sha-hmac, AH: none

Figure 21 Overhead of IPsec vs IP Payload

4.1.5. Impact of traffic mix and packet size distribution on overheads

We consider here how the traffic mix can impact the transport protocol and IPsec overheads. Figure 22 shows the methodology: Nominal packet size distributions for four example different traffic types are combined together in different mixes to result in a joint packet size distribution. We then consider the overhead of carrying a given IP packet size over the transport, adding around 90 bytes of headers for: GTP-U, UDP, IP and IPsec. The IPsec header includes padding and so varies with packet size. This overhead may vary depending on the configuration.

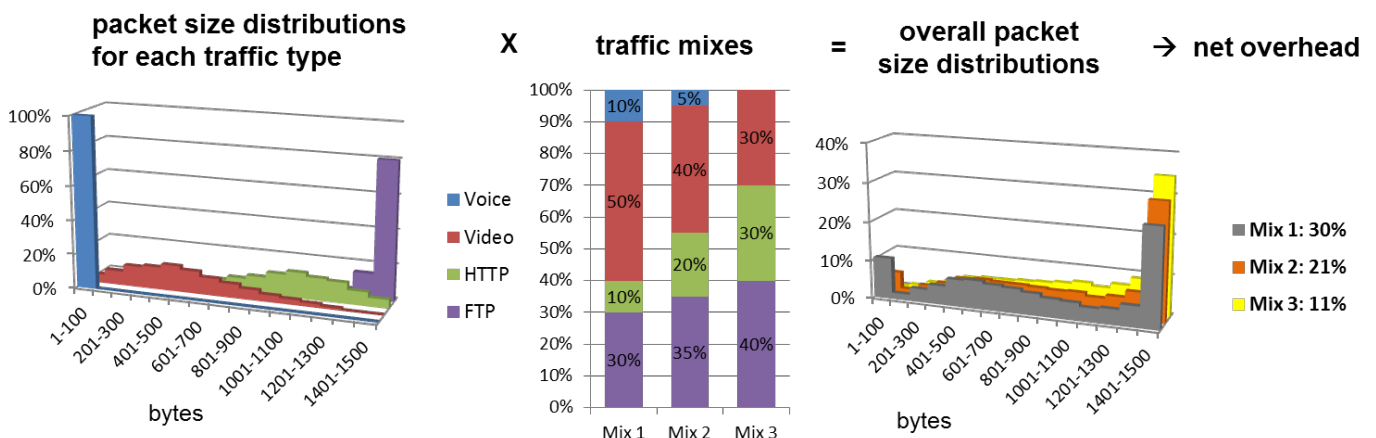


Figure 22 Impact of traffic mix on packet size distribution and transport overhead (includes IPsec)

Mix 1 is small packet heavy and results in a higher transport overhead of 30%. Mix 3 contains traffic with larger packets and thus has a lower overhead of 11%. Mix 2 sits between these extremes with 21% overhead.

These are indicative figures based on high level analysis. Operators should ideally measure or predict the actual packet size distributions and relative volumes of different traffic types in the mix to be carried over the transport. In our earlier studies, the NGMN assumed a 10% overhead for the transport protocol plus a 14% overhead for IPsec, totalling 24% [13]

5. Conclusions

This report augments a previous analysis of the backhaul capacity needed for LTE release 8 networks, by considering the impact of upgrades to LTE-Advanced features within release 10. There is no one feature set representing LTE-Advanced, rather a number of techniques which each apply in different situations: For the super-macro site where space is available, LTE-Advanced enables additional MIMO antennas, increasing both cell average capacity and peak rates. Where additional spectrum is available, carrier aggregation enables this to be efficiently accessed. Where operators have very limited space to deploy equipment, LTE-Advanced facilitates network densification with small cells, adding eICIC to co-ordinate interference between macro and small cells sharing the same spectrum. For operators with access to low cost fibre transport, Centralised or Cloud-RAN architectures with CoMP (Co-ordinated Multi-Point) can exploit interference between cells to enhance data rates for users at the cell edge.

With LTE-Advanced, it is not so much the feature itself which provides the benefit, but the increases in spectrum, site density and MIMO antennas that the features enable.

When evaluating backhaul capacity, it is the site configuration in terms of antennas, cells per site and total MHz of spectrum which dominate the calculation. LTE-Advanced features then typically increase cell average capacity between 30 and 75% compared to a similar configuration with LTE release 8.

We consider also overheads added to user data in order to transport it from base station to core network in a secure manner. Since overheads are fixed in size, the relative proportion depends on the packet sizes of user plane data. A high level analysis shows that a traffic mix with voice and video results in a higher proportion of smaller packets than would be the case where file transfer is more dominant. Overheads ranged from 11-30% in our example traffic mixes. These overheads apply equally to LTE release 8 and LTE-Advanced.

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