White Paper

Combining Innovative Radios in Area-Licensed & Unlicensed 60 GHz Spectrum Maximizes Small-Cell Backhaul Performance

Contents

1. Executive Summary

Small-cell deployment is being considered by mobile operators around the world as a means to satisfy the ever-increasing mobile broadband traffic requirements in urban areas.

Due to the need for deploying a very large number of mobile base stations on existing support structures at street-level, such as lamp posts, a number of problems have to be addressed and cost-effective backhauling is one of the major issues.

Wireless microwave (MW) systems have dominated the backhaul of macro mobile base stations in most areas of the world but for this application their characteristics need significant adaptations. The radios should be designed to combine operational versatility and flexibility in elegant-looking and compact form-factors. Furthermore, the use of area-licensed MW spectrum and unlicensed 60 GHz spectrum is suited to a number of small-cell backhaul characteristics.

Chapter 2 in this paper presents a case study of how software-defined Point-to-Point (PtP) / Point to Multi-Point (PtMP) MW radios can be combined with PtP 60 GHz radios to optimize the performance of a small-cell backhaul network, while maintaining its robustness. In the first part of the case study, a backhaul network design utilizing a limited amount of area-licensed spectrum is presented. In the second part, the selective replacement of some of the MW links by high-capacity 60 GHz radio links is shown to facilitate radio planning and improve the capacity of the network.

2. The Advantages of Using Area-Licensed MW & Unlicensed 60GHz Spectrum for Small-Cell (SmC) Backhaul

2.1. Introduction

Currently, mobile operators are closely examining wireless systems that operate in all frequencies – from sub-6 GHz (licensed and unlicensed) to 6 – 42 GHz MW to 60 GHz (V-Band) and 70 / 80 GHz (E-Band) – for the purpose of Small-Cell (SmC) backhauling.

Of particular interest is the use of Point-to-Point (PtP) / Point to Multi-Point (PtMP) systems operating in the 26 / 28 / 32 / 42 GHz area-licensed bands, as well as in the 60 GHz unlicensed band.

Both PtP and PtMP technologies share the advantage of using, either, relatively low-cost area-licensed or unlicensed spectrum, to expedite dense link planning and deployment at a minimum of licensing-related delays and costs. They also share a combination of beneficial features such as high capacity, due to the available large channel sizes, and small equipment size, due to the operation at high frequencies.

2.2. Operation in Area-Licensed Frequencies

Many operators already possess, or consider acquiring, area-licensed spectrum and would like to take advantage both of their investment and the extra assurance offered by licensed spectrum with respect to interference, in order to deploy small-cell backhaul in these frequencies.

Owning area-licensed spectrum (as opposed to per-link licensed spectrum) enables the use of PtMP systems and offers the advantage of not requiring a separate licensing procedure for the planning and installation of each link, which is a consideration if one has to deploy – and potentially – re-deploy multiple links within a short period of time.

PtMP technology, wherever applicable, improves equipment CapEx and implementation time by minimizing the number of deployed units (N+1 radio units for N links).

Licensed spectrum for the bandwidth-rich, area-licensed 26 / 28 / 32 / 42 GHz bands, usually comes at a reasonable price, especially considering the dense link deployment intended for small-cell backhaul. The benefit of using licensed spectrum is the assurance of avoiding interference from competitive operator systems using the same bands.

Nevertheless, depending on the amount of PtMP spectrum owned by an operator and the relative locations of the deployed links, the deployed backhaul links in some cases may suffer from interference due to high link density and the imposed high frequency reuse. This interference can lower the SINR and force the links to operate at lower capacities than it would otherwise be possible.

2.3. Operation in Unlicensed Frequencies

V-Band (60 GHz) technology offers license-free operation, in many countries around the world, combined with high capacity. These are considerable advantages for the cost-sensitive but demanding 4G small-cell backhaul application. This is why there is currently significant interest from the mobile operator community regarding this alternative solution.

The unlicensed operation at 60 GHz creates the potential for an amount of interference from closely located links belonging to the same or different operators, which is, in any case, greatly inferior to the interference potential of unlicensed systems at 5 GHz.

The particular characteristics of radiation propagation at 60 GHz (rapid propagation attenuation, narrow antenna beamwidths, small reflections), combined with the interference blocking result of urban street-level clutter, enhances the possibility of deploying dense networks of multiple 60 GHz links operating with a minimum of interference.

Furthermore, the spectrum available in the 60 GHz band allows for multiple channels, which can be used judiciously to minimize interference even in dense link deployment scenarios.

3. Case Study: SmC Backhaul Using 28 GHz & 60 GHz Spectrum

The case study presented in this paper shows how MW and 60 GHz spectrum technologies can be combined together in a synergistic fashion to optimize the capacity of a small-cell backhaul network, while maintaining its robustness at the same time.

Fig. 1 below depicts the small-cell network to be backhauled. This network consists of sixteen small cells (SMC1 to SMC16) distributed across a European city's hotspot areas. The backhaul network can be designed with satisfactory performance by using area-licensed MW spectrum or by using 60 GHz systems only.

For the particular case study, it is assumed that the spectrum available for the deployment of the backhaul network consists of 56 MHz of FDD spectrum in the 28 GHz band. This is a modest allocation of spectrum that an operator may easily possess given the large size of the 28 GHz band.

Option 1: Initial RF Plan & Network Performance

The backhaul network arising from the design optimally consists of a mix of sixteen PtP and PtMP links that are selected based on the particular relative locations of the small cells. In this basic scenario, the link range varies between 680m and 80m.

The backhaul traffic is aggregated in two locations (POP1, POP2). PtMP links are used, when possible, as last-hop links. Fig. 1 below depicts the frequency plan results of the reference design that uses 2 x 28 MHz channels.

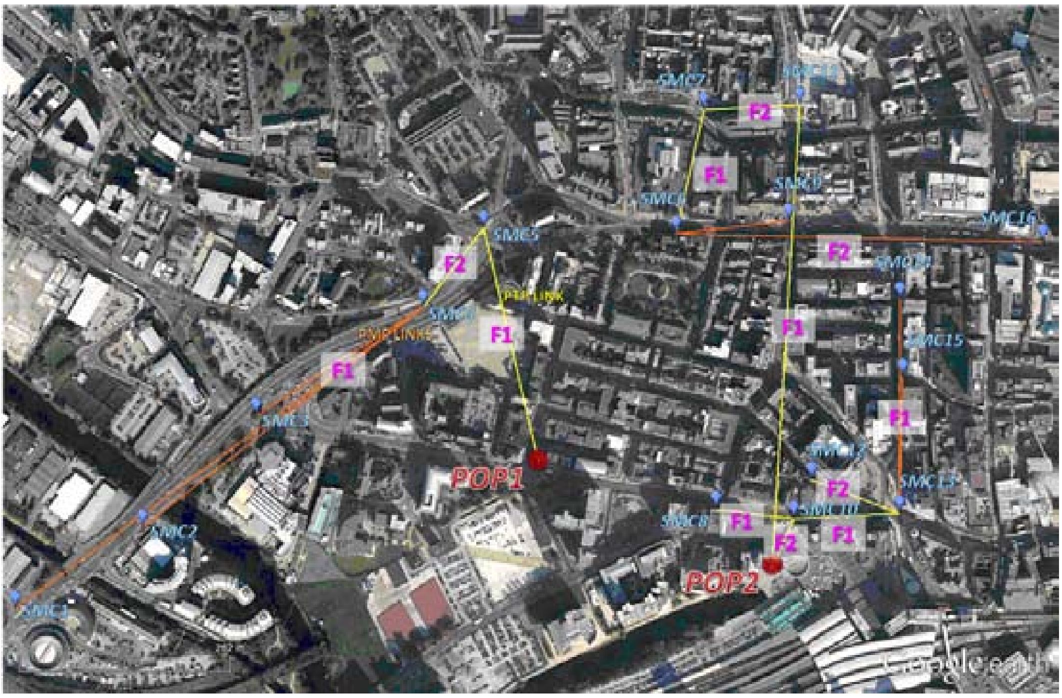

Fig. 1: Distribution of small cells in a European city (shown in blue) and the links used for their backhauling. PtP links are shown in yellow lines and PtMP links in orange lines. The traffic from the Small cells is aggregated at the two POP locations (shown in red). The frequency plan of the network using 2 x 28 MHz channels is also shown on the figure by denoting the frequency channels or the links as F1 or F2 in white background.

Table 1 gives the link SINR values, which result from the performed interference analysis of the network. These values are satisfactory to the point of allowing very high order modulation formats.

The use of 2 x 28MHz channels provides a link throughput shown in column "Link Capacity". The capacity varies between 113 Mbit/s and 69 Mbit/s (for PtMP links) and between 311 Mbit/s and 255 Mbit/s (for PtP links).

Whenever a PtP link carries traffic from more than one small cells, then the link capacity is considered to be allocated equally among each small cell.

The number of small cells served by a link and the per-cell available capacity are shown in columns "Number of Backhauled Small Cells" and "Average Capacity per Small Cell (Mbit/s)".

The capacity of each PtMP sector is equally distributed among the terminals of the sector. The throughput values in table 1 correspond to downlink direction only, as load is heavier than the uplink direction in 3G and 4G networks.

The points being demonstrated by this case study are similarly valid for the uplink direction.

Table 1: RF planning results for the Small Cell Backhaul network links using 2 x 28MHz channels

Link Site A	Link Site B	Link Type	Band (GHz)	Channel Size (MHz)	No. of Backhauled Small Cells	Link Length (m)	SINR (dB)	Modulation Mode	Link Capacity (Mbps)	Average Capacity Per Small Cell (Mbps)
POP1	SMC5	PtP	28	28	5	326.2	40.1	1024-QAM	254.5	50.9
SMC10	SMC13	PtP	28	28	4	139.3	38.6	1024-QAM	254.5	63.6
SMC13	SMC12	PtP	28	28	1	124.3	52.5	4096-QAM	311.2	311.2
POP2	SMC10	PtP	28	28	6	80.6	57.2	4096-QAM	311.2	51.9
SMC5	SMC4	PtP	28	28	4	117.0	52.6	4096-QAM	311.2	77.8
POP2	SMC11	PtP	28	28	5	138.0	39.1	1024-QAM	254.5	50.9
SMC11	SMC7	PtP	28	28	4	621.4	53.1	4096-QAM	311.2	77.8
SMC7	SMC6	PtP	28	28	3	131.3	50.1	4096-QAM	311.2	103.7
SMC10	SMC8	PtP	28	28	1	176.5	54.2	4096-QAM	311.2	311.2
SMC6	SMC9	PtMP	28	28	1	155.1	47.6	1024-QAM	113.3	113.3
SMC6	SMC16	PtMP	28	28	1	494.2	35.2	256-QAM	113.3	113.3
SMC4	SMC3	PtMP	28	28	1	270.7	40.9	1024-QAM	68.6	68.6
SMC4	SMC2	PtMP	28	28	1	481.6	38.0	256-QAM	68.6	68.6
SMC4	SMC1	PtMP	28	28	1	680.4	34.8	128-QAM	68.6	68.6
SMC13	SMC15	PtMP	28	28	1	183.1	38.5	1024-QAM	113.3	113.3
SMC13	SMC14	PtMP	28	28	1	287.1	37.2	256-QAM	113.3	113.3

Such values of backhaul capacities (per small cell) have been shown to be satisfactory for LTE small cells operating in 20 MHz channels and in 4x2 MIMO modes, in combination with category 4 terminals (see references, [1]).

A higher capacity requirement could be generated by a RAN upgrade to LTE-Advanced technology, in which case the backhaul network capacity may also need to be upgraded.

Option 2: Revised RF Plan & Performance – Using a Single 56 MHz Channel

One available option to increase the backhaul network capacity is to use a 56 MHz channel size to design the backhaul. If no additional spectrum can be obtained by the operator, then the 2 x 28MHz available channels (assuming they are contiguous) can be used to obtain a single 56 MHz channel.

The use of a channel with double the bandwidth will increase the network capacity to the degree that the elevated interference levels, caused by the increased frequency reuse, do not cause link spectral efficiency degradation by more than a factor of 2.

The RF planning results when using a single 56 MHz channel in the 28 GHz band, are shown in Table 2.

Table 2: RF planning results for the small-cell backhaul network links using a single 56 MHz channel

Link Site A	Link Site B	Link Type	Band (GHz)	Channel Size (MHz)	No. of Backhauled Small Cells	Link Length (m)	SINR (dB)	Modulation Mode	Link Capacity (Mbps)	Average Capacity Per Small Cell (Mbps)
POP1	SMC5	PtP	28	56	5	326.2	29.96	128-QAM	339.0	67.8
SMC10	SMC13	PtP	28	56	4	139.3	27.95	128-QAM	339.0	84.7
SMC13	SMC12	PtP	28	56	1	124.3	29.24	256-QAM	396.2	396.2
POP2	SMC10	PtP	28	56	6	80.6	48.5	4096-QAM	624.7	104.1
SMC5	SMC4	PtP	28	56	4	117.0	37.42	1024-QAM	510.7	127.7
POP2	SMC11	PtP	28	56	5	138.0	24.35	64-QAM	282.2	56.4
SMC11	SMC7	PtP	28	56	4	621.4	39.25	512-QAM	453.5	113.4
SMC7	SMC6	PtP	28	56	3	131.3	31.85	256-QAM	396.2	132.1
SMC10	SMC8	PtP	28	56	1	176.5	48.44	4096-QAM	624.7	624.7
SMC6	SMC9	PtMP	28	56	1	155.1	33.8	256-QAM	183.8	183.8
SMC6	SMC16	PtMP	28	56	1	494.2	31.05	64-QAM	183.8	183.8
SMC4	SMC3	PtMP	28	56	1	270.7	36.75	512-QAM	117.3	117.3
SMC4	SMC2	PtMP	28	56	1	481.6	34.6	128-QAM	117.3	117.3
SMC4	SMC1	PtMP	28	56	1	680.4	31.6	64-QAM	117.3	117.3
SMC13	SMC15	PtMP	28	56	1	183.1	33.59	256-QAM	192.6	192.6
SMC13	SMC14	PtMP	28	56	1	287.1	32.47	128-QAM	192.6	192.6

As shown in Table 2, the use of a single channel results in SINR drop by an average of 10 dB, mainly due to the interference arising from the increased frequency reuse. Consequently, the spectral efficiencies of some of the links have also dropped.

Despite this degradation, the benefit of interference blocking by the city structures allows for high enough link SINR operation to enable an average capacity improvement by about 60%.

For the particular case under examination, the capacity improvement for doubling the size of the channel ranges from 100% to 27% on a link-per-link basis.

Option 3: RF Plan & Performance – Partially Combining 28 GHz & Unlicensed 60 GHz Spectrum

The selective use of 60 GHz band links can reduce interference, improve the MW link SINR and further improve the link capacity. The alternative frequency planning using a mix of 28 GHz and 60 GHz spectrum is shown in Fig. 2.

Four PtP links 28 GHz have been substituted by four PtP links 60 GHz using two FDD channels of 250 MHz bandwidth. The capacity of such links, under the particular SINR conditions, can exceed 1 Gbit/s for a modulation format of 64-QAM.

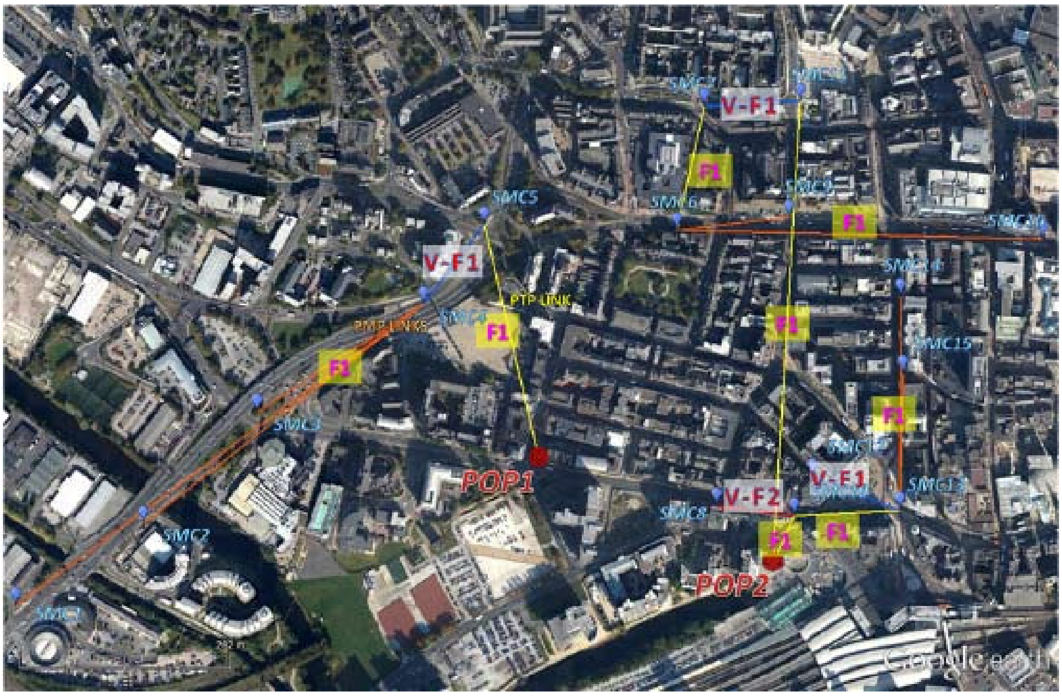

Figure 2: Distribution of Small Cells in a European city (shown in blue) and the links used for their back-hauling. PtP MW links are shown in yellow and PtMP MW links in orange (all use the same 56 MHz channel denoted as F1 in yellow background). The 60 GHz links are shown as lines in Blue (channel V-F1) and Red (channel V-F2).

The RF planning results, using a single 56 MHz channel in the 28GHz band and two channels in the 60 GHz band, are shown in Table 3. The replacement of the particular 28 GHz links by 60 GHz ones helps improve the SINR of several links by up to about 10 dB. The average SINR improvement of the 28 GHz links is about 3 dB.

Table 3: RF planning results for the small-cell backhaul network links using 1 x 56MHz channel at 28 GHz and 2x250 MHz channels at 60 GHz

Link Site A	Link Site B	Link Type	Band (GHz)	Channel Size (MHz)	No. of Backhauled Small Cells	Link Length (m)	SINR (dB)	Modulation Mode	Link Capacity (Mbps)	Average Capacity Per Small Cell (Mbps)
POP1	SMC5	PtP	28	56	5	326.2	38.93	1024-QAM	510.7	102.1
SMC10	SMC13	PtP	28	56	4	139.3	38.47	1024-QAM	510.7	127.7
SMC13	SMC12	PtP	60	250	1	124.3	40.76	64-QAM	1165.0	1165.0
POP2	SMC10	PtP	28	56	6	80.6	49.75	4096-QAM	624.7	104.1
SMC5	SMC4	PtP	60	250	4	117.0	41.73	64-QAM	1165.0	291.2
POP2	SMC11	PtP	28	56	5	138.0	28.73	256-QAM	396.2	79.2
SMC11	SMC7	PtP	60	250	4	621.4	34.58	32-QAM	867.0	216.7
SMC7	SMC6	PtP	28	56	3	131.3	31.94	512-QAM	453.5	151.2
SMC10	SMC8	PtP	60	250	1	176.5	43.01	64-QAM	1165.0	1165.0
SMC6	SMC9	PtMP	28	56	1	155.1	33.8	256-QAM	183.5	183.8
SMC6	SMC16	PtMP	28	56	1	494.2	31.12	64-QAM	183.5	183.8
SMC4	SMC3	PtMP	28	56	1	270.7	37.9	512-QAM	131.5	131.4
SMC4	SMC2	PtMP	28	56	1	481.6	35.0	256-QAM	131.4	131.4
SMC4	SMC1	PtMP	28	56	1	680.4	31.8	64-QAM	131.4	131.4
SMC13	SMC15	PtMP	28	56	1	183.1	38.74	1024-QAM	208.2	208.2
SMC13	SMC14	PtMP	28	56	1	287.1	36.09	256-QAM	208.2	208.2

Due to the interference reduction achieved by the mixed use of 60 GHz and 28 GHz spectrum, the modulation formats / spectral efficiencies of the remaining MW links have been improved.

The resulting 28 GHz link average capacity improvement is an additional:

- 17% over the single 56 MHz channel design, and
- 90% over the 2x28 MHz channel design.

The total network capacity improvement, including the high-capacity 60 GHz links, is:

- 44% over the single 56 MHz channel design, and
- 120% over the 2x28 MHz channel design.

The above results demonstrate how the combined use of area-licensed MW spectrum and 60 GHz spectrum can minimize interference and lead to a network of higher capacity / density than would be possible by using a single spectrum band.

The use of licensed MW spectrum offers increased assurance against third-party originating interference and therefore increases the overall network robustness. It also offers higher tolerance to potential partial obstructions to the link LOS (caused for example by a row of lamp posts) that may arise in some cases.

4. SmC Backhaul Challenges Drive Wireless Equipment Innovation

For many years, the use of MW systems has dominated the backhauling of macro base station sites. A new generation of systems is coming out of the development labs of the wireless equipment manufacturers specifically designed to meet the particular requirements and challenges of space and range-limited street-level deployments. Small equipment form factors, deployment speed and flexibility (on walls and lamp posts with basic powering facilities), combined with a fraction of the macro-sites CapEx/ OpEx, are the set of purpose-specific operator requirements that is driving a number of new innovative products to appear on the market.

Small-cell deployment is characterized by the peculiarity that the units are deployed at below building rooftop heights and on city structures (street lamp posts, sign posts, building sidewalls, etc.) and, in principle, at high density. Consequently, wireless backhaul links are likely to be subject to obstructions arising from city clutter such as trees, posts, buildings, etc. Such deployment characteristics, combined with the smaller coverage area per cell, create specific mechanical, functional and economical requirements for the small cells and their means of backhauling.

The grid-like nature of the streets and the obstructions imposed by city clutter at street level, necessitate the deployment of a combination of “chain”, “tree”, “star” and even “ring” configurations. Such topologies can ideally be accommodated by radio operation in PtP, relay and add/drop, and PtMP modes, capabilities that can today be supported by innovative PtP / PtMP systems.

Such an example is the StreetNode™ software-defined radio platform, which was designed and developed by Intracom Telecom. StreetNode™ specifically addresses the challenges of small-cell backhaul, enabling operators to deploy backhaul networks of any complex configuration in the 26 / 28 / 32 / 42 GHz and 60 GHz bands and realizing the benefits of increased network capacity and robustness under a single management system.

5. References

[1] “Small Cell Backhaul Requirements”, NGMN Alliance, June 2012.

6. Glossary

AAS	Advanced Antenna System
CapEx	Capital Expenditure
FDD	Frequency Division Duplex
HSB	Hot Standby
IP	Internet Protocol
LOS	Line Of Sight
LTE	Long Term Evolution
MW	Microwave
NLOS	Non Line Of Sight
NMS	Network Management System
OpEx	Operational Expenditure
PtMP	Point-to-MultiPoint
PtP	Point-to-Point
QAM	Quadrature Amplitude Modulation
RLA	Radio Link Aggregation
SmC	Small-Cell
TDM	Time Division Multiplexing
UMTS	Universal Mobile Telecommunications System
WLAN	Wireless Local Area Network
XPIC	Cross Polarization Interference Cancellation

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