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TECHNICAL REPORT

Fixed Radio Systems;
New PtMP technologies and solutions
for microwave backhaul in 5G era

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

Modal verbs terminology

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Executive summary

The 5th Generation of Access Network (5G) has raised new requirements for backhaul networks. Besides the traditional solutions using higher frequency bands e.g. W/D bands, which are suitable to transport multi-Gbit/s over several hundred meters due to large channel bandwidths but limited by almost flat gas attenuation and rain attenuation, a new PtMP structure is applicable when transmission distance is for example from 1 km to 5 km, when the room for the antennas is limited in the hub site and when it is not so easy to get higher frequency bands such as W/D band in some country/area.

The new PtMP structure operates within traditional frequency bands where block license is allowed for traditional PMP applications, such as 26/28/32/42 GHz, by using sectored multi-beam antennas to connect multiple leaf sites with a variety of multiplexing method/ multiple access method such as TDM/TDMA, FDM/FDMA, SDM/SDMA or any combinations of those above.

In the present document, the effectiveness of evolving new technologies enabling the new PtMP structure are discussed and addressed. These include: phase array antenna, beam-forming/beam nulling, side lobe interference mitigation, radiated test, etc.

Furthermore simulation results are provided to identify the appropriateness of new PtMP structure for backhaul networks with longer transmission distance, reduced required antenna number, high transmission capacity and adaptation to star-based topology in dense network area.

1 Scope

The present document discusses and addresses the effectiveness of evolving new technologies and new PtMP structures, including phase array antenna, beam-forming/beam nulling, side lobe interference mitigation, and radiated test to answer the challenges of the coming 5G backhaul network, in frequency bands above 50 GHz and lower frequency bands where PtMP/block license is allowed, such as 26/28/32/42 GHz.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ECC Report 173 (04-2018): "Fixed Service in Europe Current use and future trends".

[i.2] Recommendation ITU-R M.2083-0: "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond".

[i.3] ETSI White Paper No. 25 (first edition): "Microwave and Millimetre-wave for 5G Transport".

[i.4] 3GPP TS 38.141-2 (V16.2.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing".

[i.5] 3GPP TR 38.803 (V14.2.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on new radio access technology: Radio Frequency (RF) and co-existence aspects".

[i.6] 3GPP TS 37.145-2 (V16.3.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Active Antenna System (AAS) Base Station (BS) conformance testing; Part 2: radiated conformance testing".

[i.7] ETSI White Paper No. 15 (second edition): "mmWave Semiconductor Industry Technologies: Status and Evolution".

[i.8] ECC Report 282: "Point-to-Point Radio Links in the Frequency Ranges 92-114.25 GHz and 130-174.8 GHz".

[i.9] Recommendation ITU-R P.837-7: "Characteristics of precipitation for propagation modelling".

[i.10] Recommendation ITU-R P.530-17: "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[i.11] ETSI GR mWT 008: "millimetre Wave Transmission (mWT); Analysis of Spectrum, License Schemes and Network Scenarios in the D-band".

[i.12] ETSI GR mWT 018: "Analysis of Spectrum, License Schemes and Network Scenarios in the W-band".

[i.13] ECC Recommendation 18(01): "ECC Recommendation of 27 April 2018 on radio frequency channel/block arrangements for Fixed Service systems operating in the bands 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz and 167-174.8 GHz".

[i.14] ECC Recommendation 18(02): "ECC Recommendation of 14 September 2018 on radio frequency channel/block arrangements for Fixed Service systems operating in the bands 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz and 111.8-114.25 GHz".

[i.15] ECC Recommendation (11)01: "ECC Recommendation of 2 February 2011 on guidelines for assignment of frequency blocks for Fixed Wireless Systems in the bands 24.5-26.5 GHz, 27.5-29.5 GHz and 31.8-33.4 GHz".

[i.16] ECC Recommendation T/R 13-02: "Recommendation T/R of 1993 on preferred channel arrangements for fixed service systems in the frequency range 22.0-29.5 GHz, revised 15 May 2010 and amended 29 May 2019".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

5G	fifth Generation of mobile networks
ADC	A/D-Converter
BEM	Block Edge Mask
CIR	Committed Information Rate
CMOS	Complementary Metal Oxide Semiconductor
DAC	D/A-Converter
DPD	Digital Pre-Distortion
DSP	Digital Signal Processing
EIRP	Equivalent Isotropically Radiated Power
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FSL	Free Space Loss
IMT	International Mobile Telecommunication
LOS	Line Of Sight
MP	Multi Point
PIR	Peak Information Rate
PMP	Point to Multi Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RPE	Radiation Pattern Envelope
SDM	Space Division Multiplexing
SDMA	Space Division Multiple Access
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TDM	Time Division Multiplexing

TDMA	Time Division Multiple Access
XPIC	cross Polarization Interference Cancelling

4 New requirement from 5G to microwave backhaul

Mentioned by many administrations and companies, 5G (IMT-2020) has been initialized at the end of 2019 or in 2020 depending on different countries. As the latest mobile technology, 5G (IMT-2020) has raised new requirements to its backhaul networks, especially microwave backhaul. Figure 1 is the famous requirements of 5G (IMT-2020) network, described in Recommendation ITU-R M.2083-0 [i.2]. From the analysis of the figure, the following requirements to microwave backhaul can be seen.

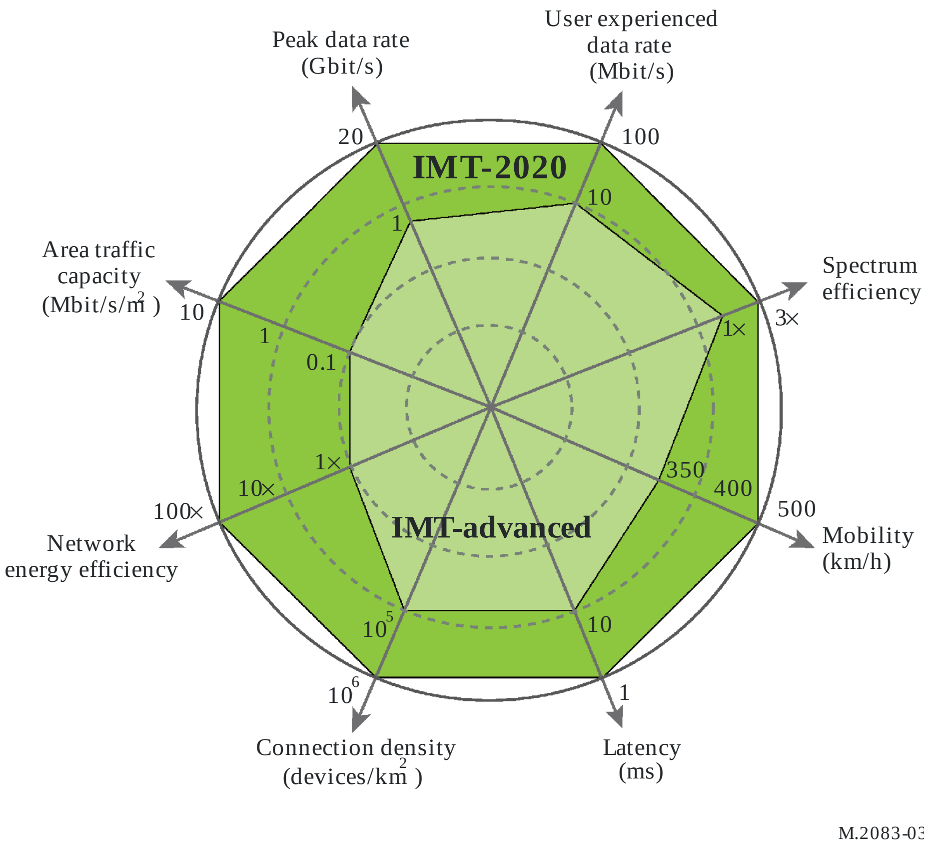


Figure 1: Enhancement of key capabilities from IMT-Advanced to IMT-2020

1) Capacity requirement. From Figure 1 above, it can be seen that the user experienced data rate will grow 10 times in 5G (IMT-2020) than in 4G (IMT-advanced). And furthermore, the peak data rate will even grow in a higher speed, 20 times in 5G (IMT-2020) than in 4G (IMT-advanced). And then researches have been done, from typical macro sites to small-cells, from dense area to urban area, from tail links to aggregation links, to determine the transport capacity requirement across the network. The result, showing the backhaul capacity requirement of 5G site, has been published in table 1, by ETSI mWT in ETSI White Paper No. 25 [i.3].

Table 1: Backhaul capacity requirement of 5G site

Site Type	Mobile spectrum and type	Cell type	Backhaul Capacity
Dense Urban	• LTE up to 50 MHz • 5G 200 MHz 16L MIMO ~4GHz • 5G ≥ 400 MHz 16L MIMO ~30GHz	Macro-cell: ~4GHz *and* ~30GHz Small-cell: ~4GHz *or* ~30GHz	>10 Gbps
Urban	• LTE up to 50 MHz • 5G 100 MHz 8L MIMO ~4GHz • 5G 200 MHz 8L MIMO ~30GHz	Macro-cell: ~4GHz Small-cell: ~4GHz *or* ~30GHz	<10 Gbps
Sub Urban	• LTE up to 50 MHz • 5G 100 MHz 8L MIMO ~4GHz	Macro-cell	<4 Gbps
Rural	• LTE up to 50 MHz • 5G 50 MHz 4L MIMO ~2GHz • 5G 20 MHz 4L MIMO ~700MHz	Macro-cell	<2 Gbps

2) Topology requirement. Also from Figure 1, area traffic capacity and connection density are both increasing in a large scale, which brings the site densification. Meanwhile, the fibre is penetrating to the edge of the network. The above two aspects have two main effects:

- Shortening of chains of cascaded radio links as the number of hops from microwave site to fibre is getting less, approaching the limit of one radio link to the fibre.

- Increase of the number of links originating from a hub site to the leaf sites.

In general, these considerations lead to define different network segments:

- Dense Urban and Urban scenarios: where previously the network was based on a hub-and-spoke kind of topology, there is a strong increase in fibre Points of Presence (PoP), from which a star topology of high capacity tail links originate; the fan-out of such hubs tends to be high. The depth of the MW/mmW network tends to become 1 to 1,5 hops from the fibre PoP.

- Sub-urban scenarios: the trend is the same, but here the MW/mmW network depth is going towards an average of 1,5 to 2 hops from the fibre PoP.

- Rural scenarios: here the variance will be greater due to the widely different geographical conditions, but it is expected that the average network depth should tend towards 2,5 hops from the fibre PoP.

- Mixed scenarios: in some places, it may happen that a small cluster of urban or suburban sites are situated at a certain distance from the fibre PoP, so that the MW/mmW link length for the aggregation link towards the PoP is not directly related to the cell radius.

As a result, the network topology, especially in dense area, is evolving from linear style to a star-based, high-capacity, and shorter distance style as shown in Figure 2. This kind of backhaul is expected to be characterized by variable behaviour, also closer to the access behaviour than for traditional backhaul. Traffic asymmetry, time variability, weather and style of living- dependent characteristics can be examples of possible sources of variability. Such new backhaul requirements could be possibly addressed by using links /network configurations other than point to point.

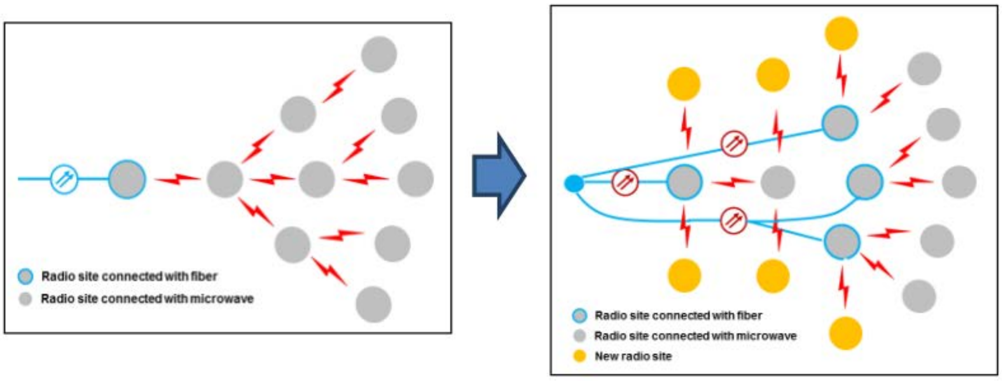


Figure 2: Topology evolution in the backhaul network

3) Mitigation of heavy burden of antenna on installation sites. Frequency resource is limited, and site resource for antennas is also limited. As for traditional PtP microwave service, each link will use one pair of parabolic antennas. As capacity increases and network topology evolves to star-based style, the number of links will increase at hub site, and then the number of antennas increases accordingly at hub site. As a result, more weight and more space are required for antenna installation site to accommodate the increasing antennas, as shown in Figure 3.

   However, the weight and space that the antenna installation site can provide is limited. In most countries, the number of antennas at the site is strictly constrained, and the application of adding new antennas on the site is also under stringent control. So the mitigation of heave burden of antenna installation site and easier installation of antennas should be taken into consideration, especially at the hub site in dense-populated area and installation over residential building.

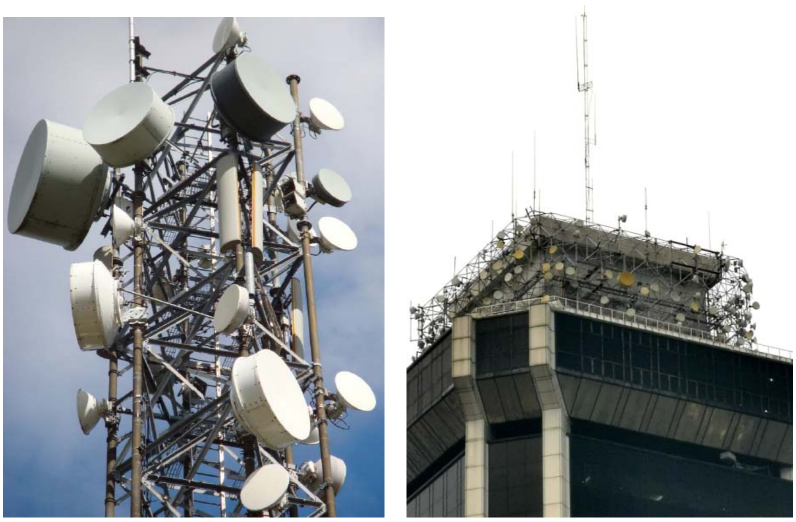


Figure 3: More antennas on installation site

According to the analysis above, traditional PtP microwave system can hardly meet the new requirements. Along with the development of communication industry, there are several new technologies emerging now, which can facilitate the adaptation to the new requirements.

5 Key technologies to facilitate adaptation to the new requirements

5.1 Active phase array antenna

The active phase array antenna is an array of antenna elements designed to change the antenna radiation pattern in order to adjust the shape and direction of the beam. In an active phase array antenna, the RF signal from the transmitter is fed to the individual antenna with the correct phase relationship so that the radio waves from separate antennas adding together increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions. In a phased array, the power from the transmitter is fed to the antennas through beamforming technology described in clause 5.2 in the present document, which can alter the phase electronically, thus steering the beam combination of radio waves to a different direction.

An active phase array antenna contains antenna array and Digital Signal Processing (DSP) running algorithms, and then make it possible for the antenna to transmit and receive signals to perform adaptation in a desired way, shown in Figure 4. A typical block diagram of a T/R module for an antenna element in an active phase array antenna in shown in Figure 5.

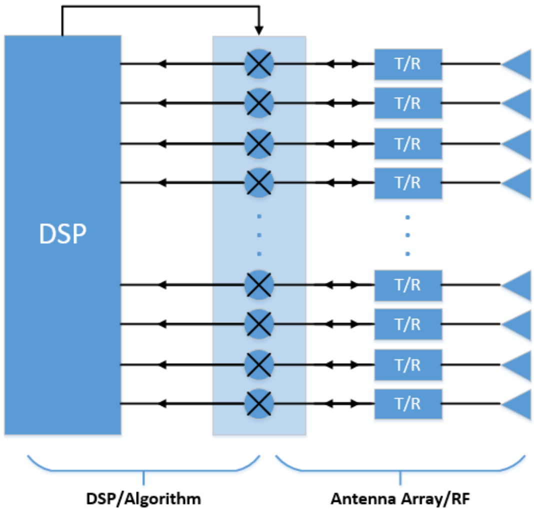


Figure 4: Block diagram of an active phase array antenna

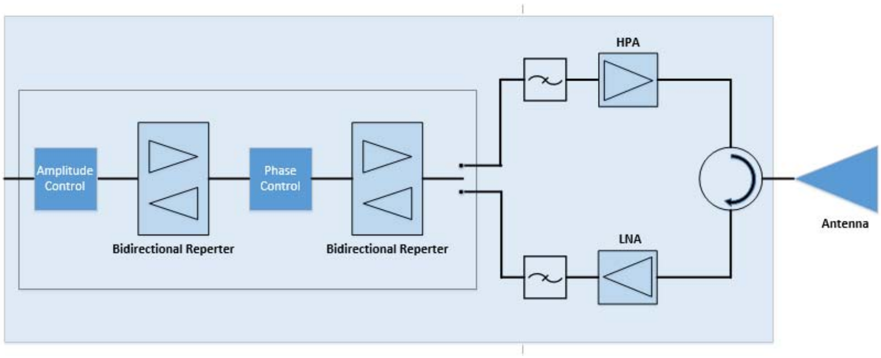


Figure 5: Block diagram of a T/R module for an antenna element in an active phase array antenna

As active antenna contains active components which are much smaller than passive components, active phase array antenna can integrate multiple array antennas inside as shown in Figure 6, with comparable size to the traditional parabolic antenna, and then make multi-antenna array implementation possible, thereby reducing the number of antennas at hub site.

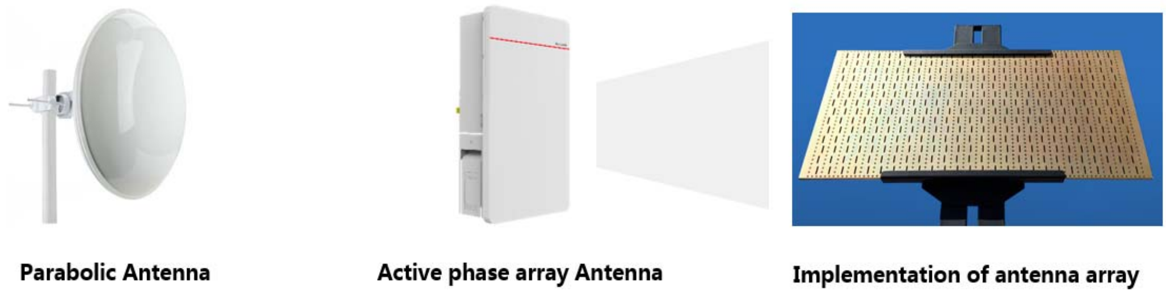


Figure 6: Parabolic antenna and integrated phase array antenna

5.2 Beamforming

Beamforming is a signal processing technology used to change the direction and the shape of radiation pattern of the array antenna for either signal transmission or signal reception. It is achieved by combining elements in the array in a way where signals at particular angles experience constructive interference and while others experience destructive interference.

Beamforming technology is used in the new PtMP structure introduced in clause 7 to automatically make alignment with hub site and leaf site. Figure 7 shows the internal diagram of beamforming. Multiple RF channel signals are transmitted at the same time and are combined in the air. The amplifier and phase shifter of each RF channel could be adjusted, in order to change the shape and phase of the beam, and then change the pointing direction of the beam combination.

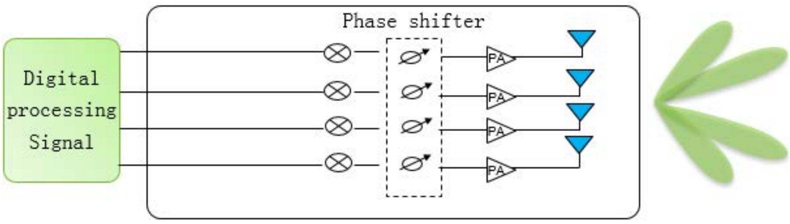


Figure 7: Internal diagram of beamforming

Figure 8 shows the operation interface and illustration of beamforming. If the four array antennas are kept with the same phase in the left figure, the combination beam just goes straight. If the phase of four array antennas are changed in the right figure, the combination beam will change its direction accordingly.

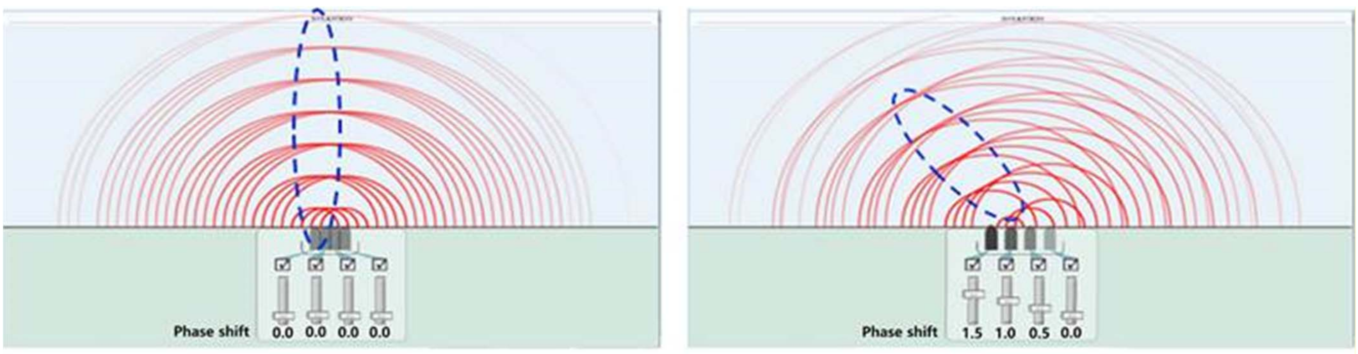


Figure 8: Operation interface and illustration of beamforming

Along with the technology development, there are several kinds of beamforming implementations:

- Analogue beamforming

Analogue beamforming typically consists of only one RF chain and only one couple of ADC/DAC (converters) and multiple analogue phase shifters that feed an antenna array, shown in Figure 9. It holds the advantages of low cost, simple structure and easy implementation, but could only produce one single beam combination at a time, and also is limited to power and performance as analogue phase shifter is used.

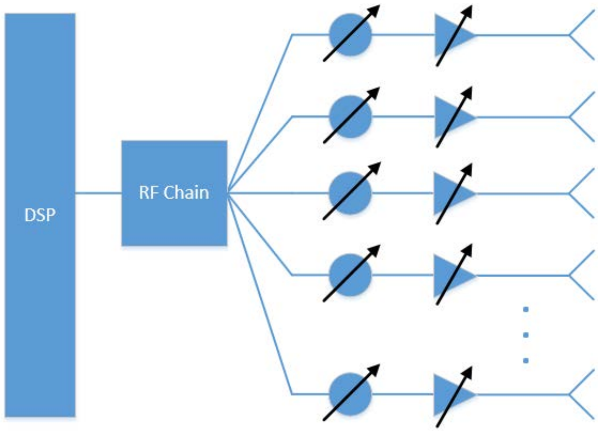


Figure 9: Analogue beamforming

- Digital beamforming.

Digital beamforming consists of multiple RF chains and multiple digital amplitude and phase shifters that feed an antenna array. In this architecture each RF chain is connected to digital converters (i.e. ADC and DAC), as shown in Figure 10. It holds more sophisticated structure than analogue beamforming, and then has higher cost and higher power consumption accordingly. However, digital beamforming can produce multiple beam combinations simultaneously, as each antenna element fed by a digital amplitude and phase shifter is connected to a RF chain. And also due to this structure, one signal could be distributed to all antenna elements through digital amplitude and phase shifter, and then could take advantage of the total gain from all the antenna elements, as a result to achieve high transmitting power. As digital shifter has higher accuracy than analogue shifter and DPD could be used, the RF performance would be increased.

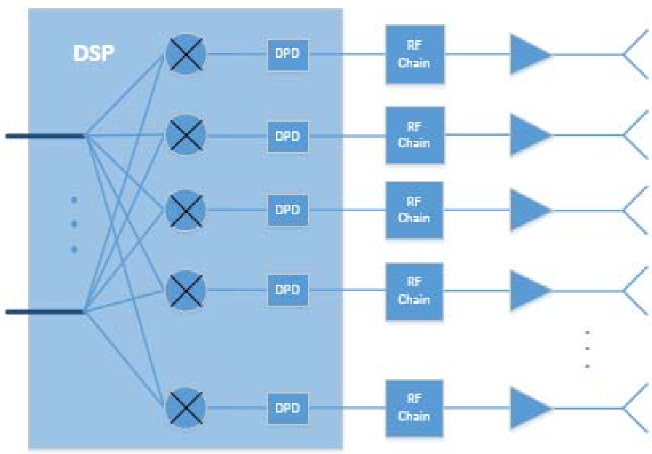


Figure 10: Digital beamforming

- Hybrid beamforming

In order to acquire balance between cost, power assumption and performance, hybrid beamforming is introduced, in which, several antenna elements fed by an analogue phase shifter are connected to a single RF chain to form a sub-array, and then several sub-arrays connected to digital amplitude and phase shifters form an antenna array, shown in Figure 11.

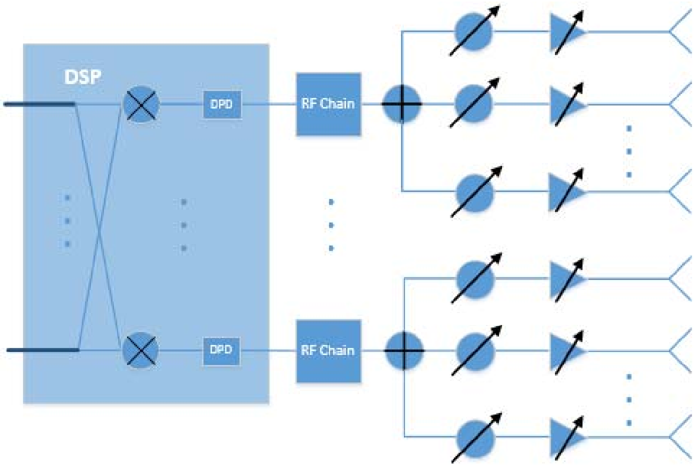


Figure 11: Hybrid beamforming

5.3 Beam nulling

Beam nulling technology is another way to reduce the interference. It is used to suppress interference which is achieved by inserting nulls in the RPE of phase array antenna in the direction of the interferences. When the main lobe of the target signal falls on the side lobes of the current signal, the side lobes would interfere with the target signal. The weight of each sub-antenna of the current signal is obtained by specific algorithms, so that the SINR of current antenna array is maximized in the desired direction, in the condition that the main lobe power of the current signal is kept unchanged, and then the side lobes are suppressed and the interference to the target signal is reduced.

An example is shown below. The network topology is depicted in Figure 12. 5 leaf sites are connected to hub site. L1 is the current signal, and L2 to L5 are the target signals. It is assumed that the main lobes of L2 to L5 just fall on the side lobes of L1. Then the side lobes of L1 would cause interference to the main lobes of L2 to L5.

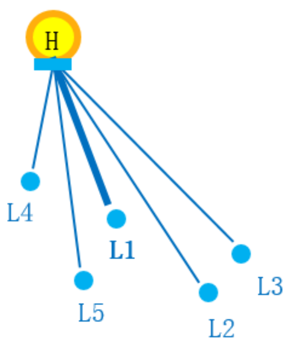


Figure 12: Network topology of an example of beam nulling

In order to minimize the interference from L1 impacting L2 to L5, specific algorithms are implemented in L1, to maximize the SINR. The other links apply the same mechanism in the other directions. The antenna radiation pattern of L1 after nulling algorithms is shown in Figure 13.

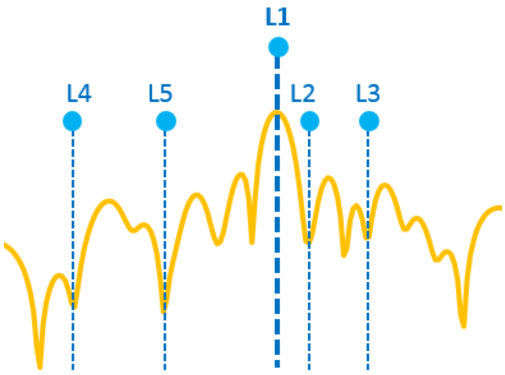


Figure 13: Antenna radiation pattern of L1 after nulling algorithms

See Annex A for more details of general algorithms.

See Annex B for simulation and lab test verification.

5.4 Interference cancellation

As multi-beam is used, each beam can cause mutual interference to the other beams, and then SINR and capacity may decrease in victim beams. To solve this problem, interference cancellation technology is introduced.

According to different transmission directions, there are two types of interference cancellation technologies.

The first type is from leaf sites to hub site. As all the signals from each link connected to leaf sites are received by hub site, interference cancellation is implemented in the receiving direction at hub site, by exchanging signals received from each leaf site to eliminate the accompanying interference, with utilization of channel matrix obtained through channel estimation algorithm.

The second type is from hub site to leaf sites. As the leaf sites are far away from each other, it is impossible to send signal from one leaf site to another leaf site. Then interference cancellation is implemented in the transmitting direction at each leaf site, by pre-coding the interference cancellation signal into the transmitting signal, with utilization of channel matrix obtained through channel estimation algorithm.

See Annex C for more details of general algorithms.

Note, for all the technologies introduced above, they are frequency independent and thus can be used in any frequency bands.

6 High frequency band with more frequency resource

To meet the new requirements from 5G to microwave backhaul, one way is to continue the exploration in higher frequency bands such as W band (92 to 94 GHz, 94,1 to 95 GHz, 95 to 100 GHz, 102 to 109,5 GHz and 111,8 to 114,5 GHz), and D band (130 to 134 GHz, 141 to 148,5 GHz, 151,5 to 164 GHz and 167 to 174,8 GHz). Naturally, more frequency resource are available in these higher frequency bands, which brings more transmission capacity.

The characteristics of W band and D band have been studied by CEPT and ETSI in recent years. Refer to ECC Report 282 [i.8] and ETSI GR mWT 008 [i.11] for D band and ETSI GR mWT 018 [i.12] for W band for details. And also the channel arrangements have been studied and published by CEPT, in ECC Recommendation 18(01) [i.13] for D band and ECC Recommendation 18(02) [i.14] for W band.

Solutions implemented by some of the key technologies introduced above in clause 5 in the present document, including active phase array antenna, beamforming, etc., could be used in W band and D band systems to make better antenna alignment as the beam in such high frequency band would be significantly narrow.

From the study above, it can be seen that, the transmission distances in W band and D band with the condition 1 Gbps/250 MHz & 1 000 MHz/99,9 % & 99,99 %/QPSK are less than 1 km. And in higher condition 10 Gbps/64 QAM, the transmission distances are around 200 m to 400 m. There are more than 16 GHz of spectrum available in the W-band, and more than 30 GHz of spectrum available in the D-band. According to large channel bandwidths and almost flat gas attenuation and rain attenuation, W band and D band are suitable for transmitting multi-Gbps in dense urban scenarios. Possible use of the W band in dense urban scenarios to allow capacities up to few Gbps is observed as less capable than the D band, due to the minor amount of available spectrum, and the higher fragmentation compared to D band.

7 New PtMP structure to increase spectrum re-usability

7.1 Introduction

To meet the new requirements from 5G to microwave backhaul, another way, when transmission distance is for example from 1 km to 5 km, the number of antennas is limited in the hub site, and it is not so easy to get higher frequency bands such as W/D band in some country/area, is to make full use of the traditional bands from 6 GHz to 42 GHz in hands.

7.2 General overview

7.2.1 General description of new PtMP structure

A new PtMP solution is a concept to meet the new requirement from 5G to microwave backhaul, through high capacity transmission, adaptation to new star-based network topology with reduced number of antennas, and easy installation with automatic antenna alignment.

The new PtMP structure is shown in Figure 14. Hub site uses sectored multi-beam antennas to connect leaf sites. Each sectored multi-beam antenna covers α° and holds *n* flows connected to *k* leaf sites. The multiplexing method could be TDM, FDM, SDM, or any combinations of those above. The multiple access method could be TDMA, FDMA, SDMA, or any combinations of those above.

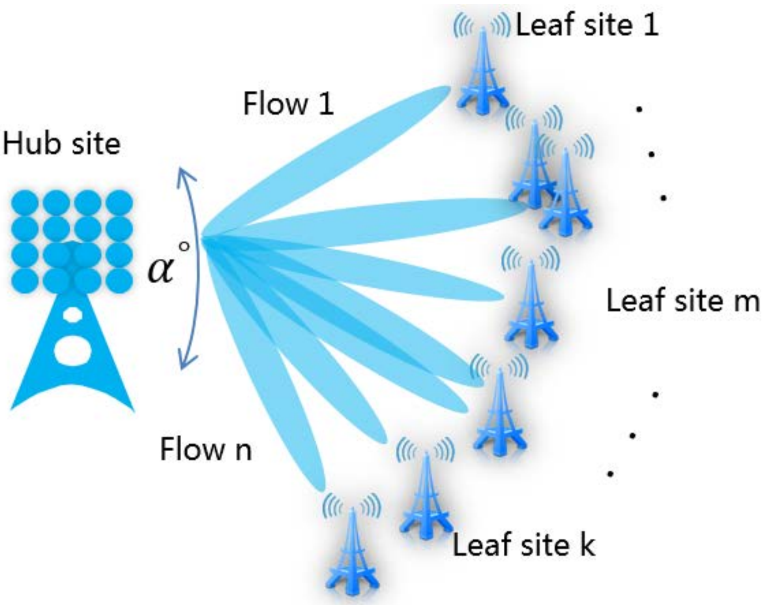


Figure 14: General structure of new PtMP systems

A logical scheme of the new PtMP solution includes increased frequency re-usability, beamforming technology and use of active phase array antenna.

Increasing transmission capacity by increasing frequency re-usability is reasonable as the frequency resource is limited in traditional bands. Using active phase array antenna can greatly reduce the number of antennas in the antenna installation sites. Active phase array antenna, together with beamforming technology, enable multi-beam adjustable in hub site, to facilitate automatic antenna alignment.

7.2.2 Network topology

The new PtMP structure is a typical **Point-to-Multipoint network topology**, which provides a communication route (on a single radio channel in each sector) from hub site to a number of leaf sites. Each hub site is either served directly from the hub site or via one or more radio repeaters. In general, each leaf site communicates with hub site by a single pathway.

7.2.3 Multiplexing method

Multiplexing method is used to multiplex together the signals from a central station to a number of Terminal Stations to allow the radio medium to be shared effectively between the various traffic paths typically under the control of the central station. The hub site of new PtMP structure could transmit signals simultaneously in all links to leaf sites with the same frequency band, so the multiplexing method would contain **SDM (Space Division Multiplexing)**, in which physical separation of transmitting (antennas) is used to deliver simultaneously different data streams from central station to multiple terminal stations.

7.2.4 Multiple access method

Multiple access method is used to provide multiple access from a number of terminal stations to one central station, thus sharing the available radio capacity into the central station between the traffic requirements of the terminal stations. The leaf sites of new PtMP structure could send signals simultaneously to hub site with the same frequency band, so the multiple access method would contain **SDMA (Space Division Multiple Access)**, in which physical separation of transmitting (antennas) is used to deliver simultaneously different data streams from multiple terminal stations to central station.

7.2.5 Duplex method

Duplex method is used to separate the two directions of signal in a bi-directional link. In the new PtMP structure, both TDD - Time Division Duplex and FDD - Frequency Division Duplex could be used as duplex method.

7.3 Key technologies to enable new PtMP structure

The new PtMP structure integrates key technologies introduced above in clause 5 in the present document, to better meet the new requirements from 5G backhaul.

Multiple beams pointing to different desired directions are produced, in order to connect to multiple leaf sites and make antenna automatic alignment, through active phase array antenna and beamforming technologies.

To enhance the frequency re-usability, beam nulling and interference cancellation technologies are used to minimize the mutual interference between each two links, and then achieve reducing the minimum angle between two links with the same frequency band.

Finally, the new PtMP structure becomes possible with multiple links from hub site to leaf sites in the same frequency band inside one antenna as well as antenna automatic alignment between hub site and leaf sites.

A simple example is shown below. A star topology network with hub site connecting to 17 leaf sites is showing in Figure 15.

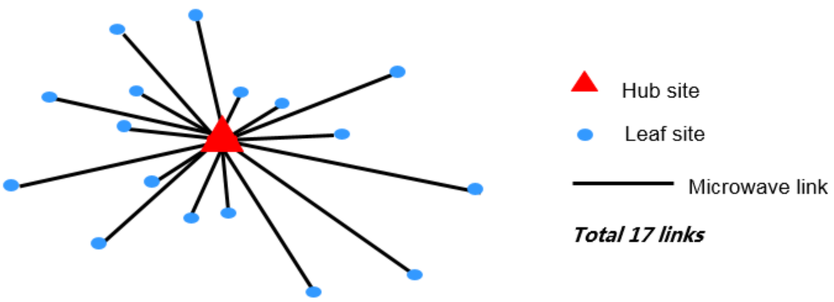


Figure 15: Example network

If new PtMP structure is implemented in this network, only one frequency band and 3 active phase array antennas are used to connect all the leaf sites to hub site, as shown in Figure 16. And also antenna installation becomes much easier as automatic beam alignment is implemented.

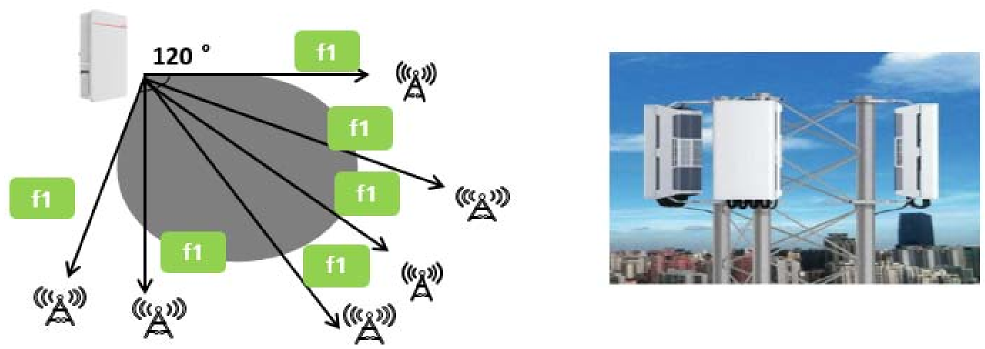


Figure 16: Antennas used in the hub site

7.4 Technical characteristics

As analysed above, new PtMP structure can exploit the technique achievements of 5G backhaul requirement, and possesses its own unique characteristics, which would gain interests from users who can benefit from these characteristics.

New multiplexing method and new multiple access method are introduced in new PtMP structure **- SDM (Space Division Multiplexing)** and **SDMA (Space Division Multiple Access)**. SDM enables delivering different data streams simultaneously from central station to multiple terminal stations by physical separation of transmitting (antennas), and SDMA enables delivering different data streams simultaneously from multiple terminal stations to central station by physical separation of transmitting (antennas). In this way, frequency re-usability and transmission capacity could be increased in a certain area, comparing to the traditional TDM/TDMA, FDM/FDMA, etc.

As one trend of antenna technology, active antenna is frequently discussed in many applications in microwave industry, and is also introduced in new PtMP structure, to enable flexibly connection from hub site to leaf sites, reduce the number of antennas at hub site and make auto alignment possible.

Since the new PtMP system uses different multiplexing method/access method and adopt new technologies such as active antenna, the characteristics of new PtMP may show some difference from traditional PmP structure. The new PtMP system consists of thousands of T/R modules, in which high integration process (BiCMOS, CMOS) is usually required to reduce the size and power consumption. As discussed in ETSI White Paper No. 15 [i.7], SiGe BiCMOS technology is well suited for highly integrated mmWave systems, especially, mmWave phased array transceivers. BiCMOS exploits its integration capabilities, not only reducing the number of chips to be assembled in the phased array but also greatly simplifying the control routing in large arrays. As a result, the introduction of high integration process brings different system performance in terms of noise figure, channel linearity and gain, etc., to traditional progress such as GaAs.

7.5 Simulation

7.5.1 Case 1 - 11 links

To verify the performance of new PtMP structure with 5G requirement, simulation has been done. The target network is shown in Figure 17. It has one hub site, and total 11 leaf sites. The capacity requirement for each link is 200 Mbps in average at availability of 99,995 %, and 1Gbps at peak at availability of 99,98 %. The channel model used for the simulations is pure Line Of Sight (LOS). Thus, usual Free Space Loss (FSL) attenuation is computed. The environment assumptions are listed in Table 2 below, according to Recommendation ITU-R P.837-7 [i.9] and Recommendation ITU-R P.530-17 [i.10].

Table 2: Environment assumptions

PARAMETER	VALUE	NOTE
Water Vapor Density	7,5 g/m^3	
Temperature	15 °C	
Pressure	1 013,25 hPa	
Refractivity Gradient	-790,549 N units/km	
Rain Rate	47,2 mm/h	0,01 % probability

The distance, angle and height information are listed in Table 3.

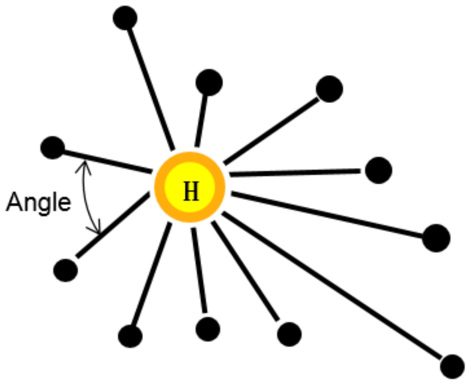


Figure 17: Target network for simulation

Table 3: Distance, angle and height information of target network

Leaf No.	Distance (km)	Angle (°)	Leaf sites height (m)	Hub site height (m)
1	1,04	37,7	256	273
2	2,60	41,4	291,5	273
3	2,67	41,9	271	273
4	3,07	26,3	241,2	273
5	3,84	32,7	235,4	273
6	2,16	12,8	225,5	273
7	1,32	18,6	231	273
8	1,75	20	201	273
9	1,68	32,1	179	273
10	1,26	34,1	214	273
11	1,22	62,3	266	273
NOTE: The distances which are greater than 3 km are shown in light blue cells.				

Simulation based on new PtMP structure has been done, by using traditional band of 28 GHz. The target network has been divided into 3 sectors as shown in Figure 18, as inter-sector interference has been taken into consideration. Beam nulling has also been done to reduce the inter-sector and intra-sector interference. In each sector one phase array antenna with 8 data streams (possible beams) is used to cover all the leaf sites inside. A phase array antenna contains 8 sub-array antennas, and in each sub-array antenna there are 16×20 antenna elements inside, with 8 dBi antenna gain for each antenna element. Hybrid beamforming is used in the simulation to steer beams from hub site to leaf sites, and implement antenna automatic alignment. The system parameters are shown in Table 4 below.

NOTE: In the system shown in this case there are 8 streams with 16×20 antenna elements in each active antenna, which means that the whole hub site will use 3×2 560 antenna elements with phase and/or amplitude control. The distance between the centres of two single antenna elements is from 0,5 λ to 0,8 λ depending on implementation.

Table 4: System parameters of new PtMP simulation

PARAMETER	VALUE	NOTE
EIRP	56 dBm 50 dBm	QPSK 16 to 256-QAM
SNR	5 dB 29 dB	QPSK 256-QAM
Noise Figure	8,5 dB	

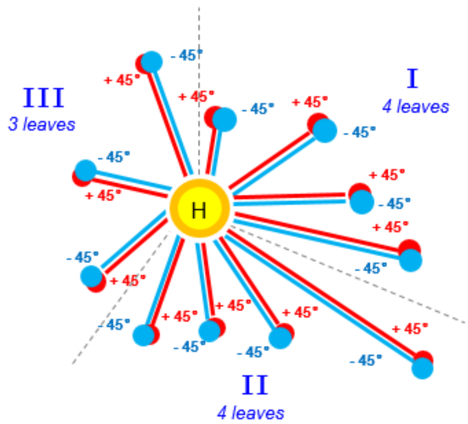


Figure 18: Division of target network

The simulation result is showing in Table 5. TDD is used in this simulation, and the capacity in the result is on downlink direction, with 4:1 downlink to uplink ratio assumption. Traditional band of 28 GHz with 200 MHz channel width is used, by XPIC. In aspect of frequency resource, as interference cancellation technology is used to greatly reduce the minimum angle between two links with the same frequency band, only one 200 MHz to 28 GHz band is used to cover all the links in the three sectors. Total of 3 active phase array antennas are used in hub site. It can be seen from the result that, both average availability and peak availability could meet the requirement.

Table 5: Simulation result based on new PtMP structure

Hub Sector	Leaf No.	PIR (1 Gbps@99,98 %)		CIR (200 Mbps@99,995 %)	
		Capacity	Availability	Capacity	Availability
1	1	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	2	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	3	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	4	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
2	5	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	6	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	7	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	8	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
3	9	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	10	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %
	11	1 003 Mbps	> 99,98 %	327 Mbps	> 99,995 %

NOTE: The aim of the simulation is to verify whether the system can meet the capacity and availability requirement, but not to test the system performance limit. So the CIR simulation stops at capacity of 327 Mbps when both the capacity and availability reach the target, it does not imply that 327 Mbps is the upper capacity limit.

Note that in some examples, only CIR is used for transmission capacity assessment.

7.5.2 Case 2 - 21 links

Simulation has been done to a more complex network structure, with one hub site and total 21 leaf sites, as shown in Figure 19. The capacity requirement for each link is 200 Mbps in average at availability of 99,995 %, and 1 Gbps at peak at availability of 99,98 %. The channel model used for the simulations is pure Line Of Sight (LOS). Thus, usual Free Space Loss (FSL) attenuation is computed. The environment assumptions are the same with case 1, as listed in Table 1 in clause 7.5, according to Recommendation ITU-R P.837-7 [i.9] and Recommendation ITU-R P.530-17 [i.10].

The distance, angle and height information are listed in Table 6.

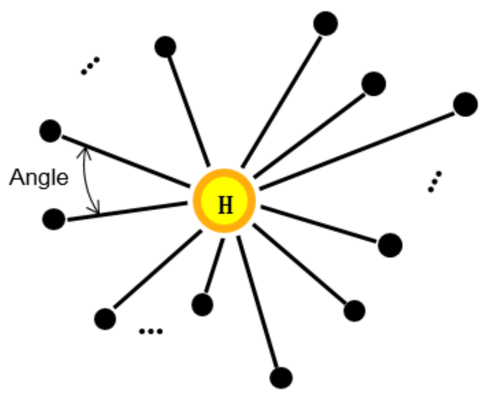


Figure 19: Target network for simulation

Table 6: Distance, angle and height information of target network

Leaf No.	Distance (kilometer)	Angle (°)	Leaf sites height (meter)	Hub site height (meter)
1	1,04	37,7	256	273
2	3,26	30,2	354,6	273
3	2,60	11,2	291,5	273
4	3,56	29,9	325,7	273
5	2,67	12,0	271	273
6	4,57	11,1	293,64	273
7	3,07	15,2	241,2	273
8	3,52	12,0	232	273
9	3,84	20,7	235,4	273
10	3,72	8,8	220,6	273
11	2,16	4,0	225,5	273
12	3,08	4,0	212,2	273
13	1,32	14,6	231	273
14	1,87	3,8	210	273
15	1,75	16,2	201	273
16	3,71	12,5	196	273
17	1,68	19,6	179	273
18	1,57	13,7	181	273
19	1,26	20,4	214	273
20	1,82	46,7	283	273
21	1,22	15,6	266	273
NOTE: The distances which are greater than 3 km are shown in light blue cells.				

Simulation based on new PtMP structure has been done, by using traditional band of 28 GHz. The target network has been divided into 3 sectors as shown in Figure 20, as inter-sector interference has been taken into consideration. Beam nulling has been done to reduce the inter-sector and intra-sector interference. In each sector one phase array antenna with 16 data streams (possible beams) is used to cover all the leaf sites inside. A phase array antenna contains 16 sub-array antennas, and in each sub-array antenna there are 16×20 antenna elements inside, with 8 dBi antenna gain for each antenna element. Hybrid beamforming is used in the simulation to steer beams from hub site to leaf sites, and implement antenna automatic alignment. The system parameters are the same with those in 11 links case shown in clause 7.5 in Table 3.

NOTE: In the system shown in this case there are 16 streams with 16×20 antenna elements in each active antenna, which means that the whole hub site will use 3×5 120 antenna elements with phase and/or amplitude control. The distance between the centres of two single antenna elements is from 0,5 λ to 0,8 λ depending on implementation.

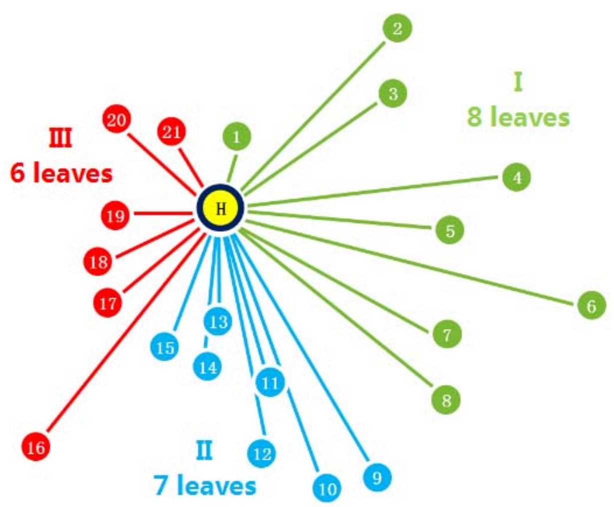


Figure 20: Division of target network

The simulation result is showing in Table 6. TDD is used in this simulation, and the capacity in the result is on downlink direction, with 4:1 downlink to uplink ratio assumption. Traditional band of 28 GHz with 200 MHz channel width is used, by XPIC. In aspect of frequency resource, as interference cancellation technology is used to greatly reduce the minimum angle between two links with the same frequency band, only one 200 MHz to 28 GHz band is used to cover all the links in the three sectors. Total 3 active phase array antennas are used in hub site. It can be seen from the result that, all links could meet the average availability requirement, but one out of total 21 links could not meet the peak availability requirement. This one link which could not meet the requirement is shown in yellow in Table 7.

Table 7: Simulation result based on new PtMP structure

Hub Sector	Leaf No.	PIR (1 Gbps@99,98 %)		CIR (200 Mbps@99,995 %)	
		Capacity	Availability	Capacity	Availability
1	1	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	2	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	3	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	4	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	5	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	6	1 000 Mbps	> 99,97 %	243 Mbps	> 99,995 %
	7	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	8	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
2	9	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	10	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	11	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	12	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	13	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	14	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	15	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
3	16	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	17	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	18	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	19	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	20	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	21	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %

After a careful network planning, optimizing the antenna orientation in the hub, all the links can meet the requirements. The target network has been re-divided into 3 sectors as shown in Figure 21. The other system parameters and simulation conditions are the same with previous one.

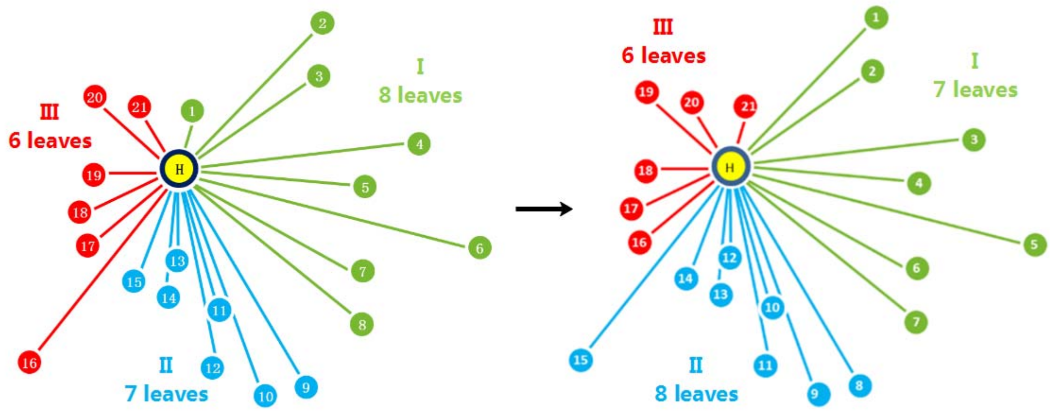


Figure 21: Re-division of target network using network planning method

The simulation result is showing in Table 8. The same frequency resource with previous one is used here. It can be seen from the result that, now both average availability and peak availability could meet the requirement.

From the analysis above, it can be seen that, network planning is an effective way to improve the performance of new PtMP solution.

Table 8: Simulation result based on new PtMP structure using network planning

Hub Sector	Leaf No.	PIR (1 Gbps@99,98 %)		CIR (200 Mbps@99,995 %)	
		Capacity	Availability	Capacity	Availability
1	1	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	2	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	3	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	4	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	5	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	6	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	7	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
2	8	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	9	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	10	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	11	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	12	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	13	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	14	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	15	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
3	16	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	17	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	18	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	19	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	20	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	21	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %

To verify the inter-sector nulling effect, another simulation has been done, in the condition that inter-sector beam nulling is not considered. The network topology is the same with previous simulation, as shown in Figure 22. The other system parameters and simulation conditions are the same with previous one.

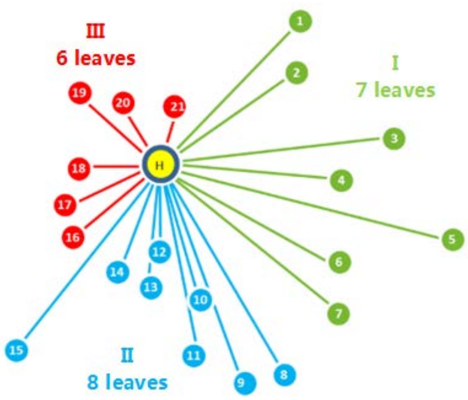


Figure 22: Network topology of simulation without inter-sector beam nulling

The simulation result is showing in Table 9. The same frequency resource with previous one is used here. It can be seen that, all links could meet the average availability requirement; but 2 out of total 21 links as shown in yellow in Table 8, could not meet the peak availability requirement. In the previous simulation where the inter-sector beam nulling is considered, those two links are able to meet peak availability requirement. From the analysis above, it can be seen that, beam nulling could effectively reduce inter-sector interference.

For RPE of active antenna used in above simulations, see Annex D for more information.

Table 9: Simulation result based on new PtMP structure without inter-sector beam nulling

Hub Sector	Leaf No.	PIR (1Gbps@99,98 %)		CIR (200Mbps@99,995 %)	
		Capacity	Availability	Capacity	Availability
1	1	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	2	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	3	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	4	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	5	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	6	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	7	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
2	8	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	9	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	10	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	11	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	12	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	13	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	14	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	15	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
3	16	1 000 Mbps	< 99,98 %	243 Mbps	> 99,995 %
	17	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	18	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	19	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	20	1 000 Mbps	> 99,98 %	243 Mbps	> 99,995 %
	21	1 000 M	< 99,98 %	243 Mbps	> 99,995 %

7.5.3 Simulation conclusion

From the analysis above, it can be concluded that, the new PtMP structure can meet the capacity and availability requirements of 5G backhaul in this specific use case, indicated in clause 7.4 of the present document. As the angle between two links with the same frequency band, in an extreme scenario, for instance in the 21 links scenario, is as low as in average 10° to 15° and even lower to 4° to 5° in some specific links, only one frequency band is used for all links in the target networks. As active phase array antenna is used to produce multiple beams inside one antenna, only 3 antennas are used in the target networks as each antenna covers 120°containing at most 8 beams inside.

8 License Scheme

8.1 Introduction

To make full use of spectrum resource in dense area through better utilization of new PtMP structure for higher spectrum reusability, license scheme plays an important role.

8.2 License scheme recommended for new PtMP structure

Current license schemes for Fixed Service contain the following several types: Individual license, Light license, License exempt and Block assignment.

Block assignment is defined as follow, taken reference to ECC Report 173 [i.1]:

*"**Block assignment** - The assignment might be made through licensing (renewable, but not permanent) or through public auction (permanent). This is most common when fixed wireless access (point to multi-point, P-MP) is concerned and the user is usually free to use the block at best to deploy its network; in some cases, there might even be no limitation to the wireless communication methods used in the block (e.g. P-P and/or P-MP, terrestrial and/or satellite or any other innovative technology or architecture). In the most popular bands for this method, ECC recommendations exist suggesting intra-block protection guidelines in terms of guard bands or block-edge masks (BEM). For some frequency bands this method is considered the best compromise between efficient spectrum usage and flexibility for the user."*

New PtMP structure is a new kind of P-MP structure. Besides the reason of using block assignment expressed above, that block assignment facilitates spectrum usage as much as possible for new PtMP structure, another important reason lies in that the interference cancellation and beam bulling are implemented through coordination of the whole network links based on block assignment.

Therefore block assignment is felt as the most appropriate license scheme for new PtMP structure.

8.3 Block assignment of 28GHz in Europe

This clause provides examples of block assignment of 28 GHz in Europe.

According to the ECC Report 173 [i.1], in 28 GHz (27,5 to 29,5 GHz) band, P-P and P-MP applications are allowed; Austria, Bosnia and Herzegovina, Greece, Slovak Republic and Latvia allow both use. The licenses in 28 GHz band can be assigned by blocks in Bosnia and Herzegovina, Czech Republic, Italy, Spain, Germany, UK, Greece, Norway, Portugal, Sweden, Latvia, Lithuania, Romania, Russia, Slovak Republic, and Slovenia.

This 28 GHz band is well harmonised, the P-P channel plan follows the ECC Recommendation T/R 13-02 [i.16], the block assignment guidance for P-MP links is provided in the ECC Recommendation (11)01 [i.15] with block size of N×28 MHz, no national frequency plan is indicated.

For example (from ECC Report 173 [i.1]), in UK, in 2008 Ofcom auctioned a number of bands (approximately 6 GHz of spectrum) on a technology neutral basis in block assignment. These include the 10 GHz, 28 GHz, 32 GHz, and 40 GHz, with block size 112 MHz and 224 MHz to 28 GHz.

Considering the condition outside Europe, many countries have not open 28 GHz yet. This facilitates the use of block license in 28 GHz in these countries.

9 Test methodology

As analysed above, active phase array antennas which are not detachable from the equipment would be used in the 5G backhaul networks, the traditional test cannot be done. The traditional test is conducted test using the antenna port detached from the antenna. However, phase array antenna is integrated antenna that, there will be no antenna port detachable. Then radiated antennas with the use of anechoic chamber and reference antennas would be required.

Radiated test is introduced to solve the problem raised above. 3GPP has done research on radiated test, and has published related technical specification; refer to 3GPP TS 38.141-2 [i.4] for more information.

Annex A: General beam nulling algorithms

This annex provides the general algorithms of beam nulling.

The array output amplitude can be expressed as:

$$\mathbf{Y} = \mathbf{W}^{\mathrm{H}}\mathbf{X} \tag{A.1}$$

In which:

$\mathbf{Y}$ is the array output amplitude, $\mathbf{W} = [w_1, w_2, \cdots\cdots, w_N]^T$ is the weight vector, $\mathbf{X} = [x_1, x_2, \cdots\cdots, x_N]^T$ is the output vector from N array elements. In general, the array element output vector is considered to be the addition of input signal and noise plus directional interference. Therefore:

$$\mathbf{X} = \mathbf{S} + \mathbf{N} \tag{A.2}$$

Where, **S** is the input signal vector and **N** is the noise plus directional interference vector. In the assumption of plane wave:

$$\mathbf{S} = \mathbf{S_0 a_s} \tag{A.3}$$

$$\mathbf{N} = [\mathrm{a}_1, \cdots\cdots, \mathrm{a_M}] \times [g_1, \cdots\cdots, g_M]^T + [n_1, \cdots\cdots, n_N]^T \tag{A.4}$$

Where:

$$\mathbf{a_s} = \left[e^{-i(2\pi f_s/c \times r d_1)}, \cdots\cdots, e^{-i(2\pi f_s/c \times r d_N)}\right]^T \tag{A.5}$$

is the direction vector of input signal;

$$[\mathrm{a}_1, \cdots\cdots, \mathrm{a_M}] = \left[\left(e^{-i(2\pi f_{g1}/c \times r_1 d_1)}, \cdots\cdots, e^{-i(2\pi f_{g1}/c \times r_1 d_N)}\right)^T, \cdots\cdots, \left(e^{-i(2\pi f_{gM}/c \times r_M d_1)}, \cdots\cdots, e^{-i(2\pi f_{gM}/c \times r_M d_N)}\right)^T\right] \tag{A.6}$$

is the direction vector matrix from M interference source;

r and *d* are coordinate vectors of each array element from signal and interference source;

$\mathbf{S_0}$ is the transmitting signal amplitude at the source;

$g_1, \cdots\cdots, g_M$ are the amplitudes of M interference sources;

$n_1, \cdots\cdots, n_N$ are the amplitudes of addictive noise.

From above equations, **Y** can be obtained as:

$$\mathbf{Y} = \mathbf{W^H S} + \mathbf{W^H N} \tag{A.7}$$

Then in the assumption that signal and interference plus noise are completely uncorrelated, the array output power is:

$$\mathbf{E[YY^H] = W^H E[SS^H] W + W^H E[NN^H] W = W^H R_{SS} W + W^H R_{NN} W} \tag{A.8}$$

In which:

$\mathbf{R_{SS}}$ and $\mathbf{R_{NN}}$ are the covariance matrix of signal and interference plus noise respectively.

And then the SINR of array is:

$$\mathrm{SINR} = \frac{\mathbf{W^H R_{SS} W}}{\mathbf{W^H R_{NN} W}} \tag{A.9}$$

From characteristics of Rayleigh entropy, the optimized weight when SINR reaches its maximum value is:

$$\mathbf{W_{\mathit{opt}}} = \mathrm{Q}\mathbf{R_{NN}^{-1} a_S} \tag{A.10}$$

The coefficient Q is the Lagrange multiplier.

From receiving signal power constraint:

$$\mathbf{W}_{\mathbf{opt}}^{\mathbf{H}}\mathbf{a}_{\mathbf{S}} = 1 \tag{A.11}$$

The coefficient Q can be obtained as:

$$\mathrm{Q} = \frac{1}{\mathbf{a}_{\mathbf{S}}^{\mathbf{H}}\mathbf{R}_{\mathbf{NN}}^{-1}\mathbf{a}_{\mathbf{S}}} \tag{A.12}$$

And then finally the optimized weight can be explained as:

$$\mathbf{W}_{\boldsymbol{o}\mathbf{pt}} = \frac{\mathbf{R}_{\mathbf{NN}}^{-1}\mathbf{a}_{\mathbf{S}}}{\mathbf{a}_{\mathbf{S}}^{\mathbf{H}}\mathbf{R}_{\mathbf{NN}}^{-1}\mathbf{a}_{\mathbf{S}}} \tag{A.13}$$

From above analysis it can be seen that, the weight vector can vary according to the change of the noise plus interference covariance matrix, and then the maximum SINR of the array output in the desired direction could be adaptively achieved.

Annex B: Beam nulling simulation and lab test verification

B.1 Introduction

This annex provides beam nulling simulation in 28 GHz, and related lab test for verification.

First, simulation of beam nulling has been done using continuous wave at 28 GHz. The RPE of a phase array antenna without applying any beam nulling, and with beam nulling at a certain angle have been synthesized.

And then, in order to verify the simulation result, related lab tests, using continuous wave at 28 GHz and using 200 MHz wide band signal with central frequency at 28 GHz, have been done in anechoic chamber built with pyramid absorbing material, The test scheme is shown in Figure B.1. For both simulation and lab tests, the consistence error has been taken into consideration.

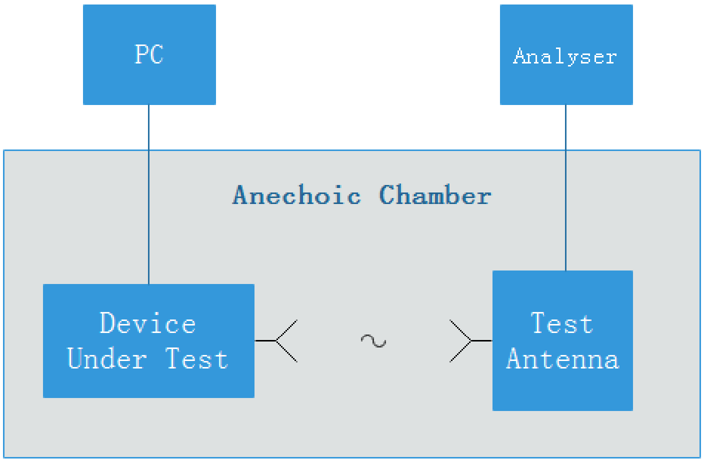


Figure B.1: Lab test scheme

The test antenna was fixed at one side of the anechoic chamber. The phase array antenna was attached to a test bench at another side of the anechoic chamber. The distance between the test antenna and the phase array antenna met the far field test condition. Refer to 3GPP TS 38.141-2 [i.4] and 3GPP TS 37.145-2 [i.6] for detailed test condition and detailed test methodology. The phase array antenna was aligned to the test antenna at its boresight. The phase array antenna transmitted continuous wave at 28 GHz, and the test bench turned 60° in horizontal plane to its right side and left side separately. The analyser took down the receiving signal every 1° for the whole 120° when the test bench turned around. The test result was drawn according to the data taken down by the analyser.

B.2 Simulation and lab test without applying any beam nulling

The RPE of phase array antenna using continuous wave at 28 GHz without applying any beam nulling has been synthesized, and the lab test of RPE using continuous wave at 28 GHz without applying any beam nulling has been done, as shown in Figure B.2.

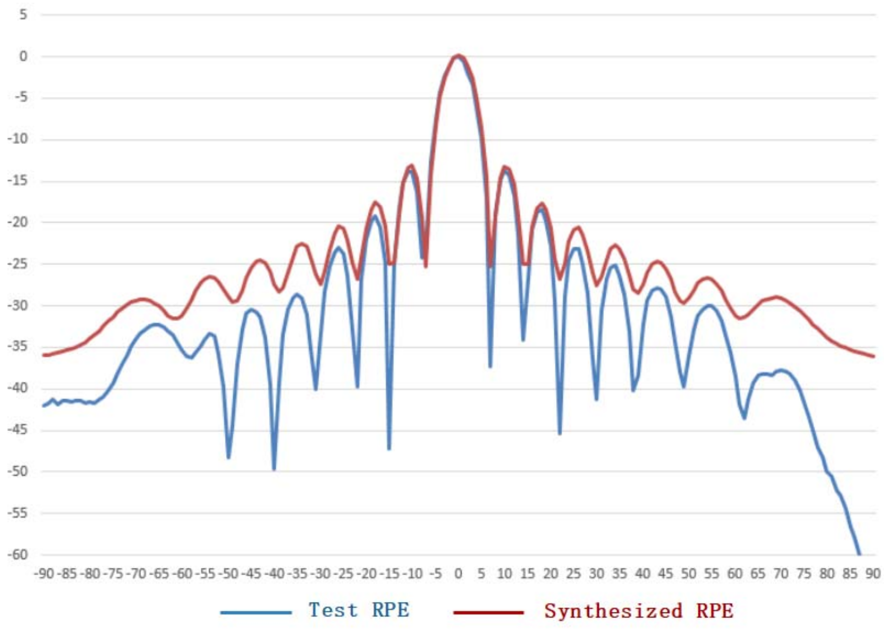


Figure B.2: Synthesized and lab test result of RPE using continuous wave at 28 GHz without applying any beam nulling

Note that as the consistency error at boresight holds the best value in actual test scenario, while average consistency error has been used in synthesizing, the test RPE is better than synthesized RPE.

The Synthesized RPE using 200 MHz wide band signal with central frequency at 28 GHz without applying any beam nulling has been done, as shown in Figure B.3.

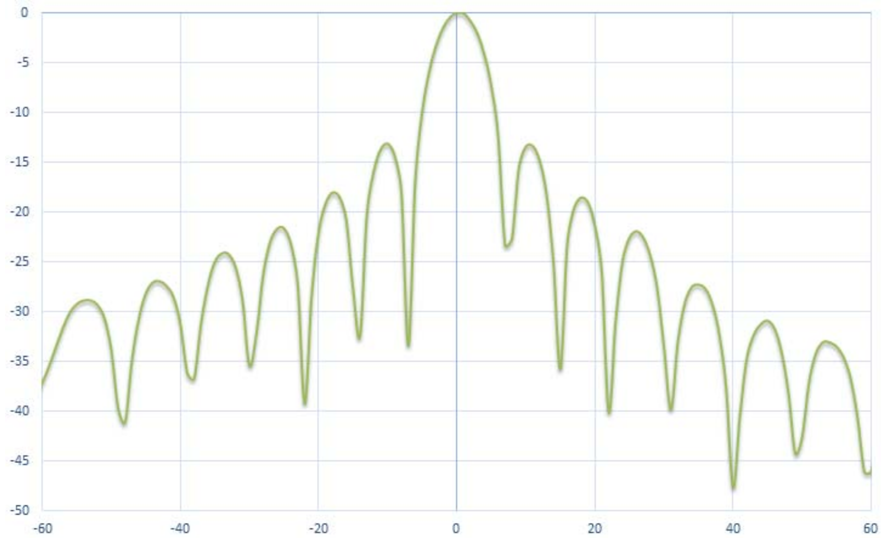


Figure B.3: Synthesized RPE using 200 MHz wide band signal with central frequency at 28 GHz without applying any beam nulling

B.3 Simulation and lab test with a null applied at 18° beside the main beam

The RPE using continuous wave at 28 GHz with a null applied at 18° beside the main beam has been synthesized, and the lab test of RPE using continuous wave at 28 GHz with a null applied at 18° beside the main beam has been done, as shown in Figure B.4.

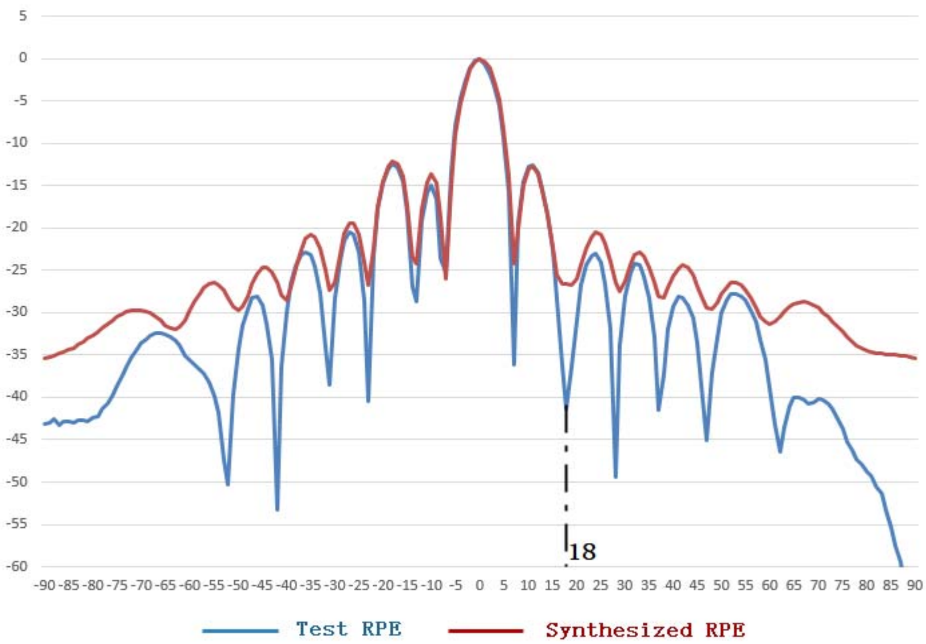


Figure B.4: Synthesized and Lab test result of RPE using continuous wave at 28 GHz with a null applied at 18° beside the main beam

The Synthesized RPE using 200 MHz wide band signal with central frequency at 28 GHz with a null applied at 18° beside the main beam has been done with the result shown in Figure B.5. It can be seen that, the nulling depth of wide channel is not as deep as that of continuous wave.

Note that as the consistency error at boresight holds the best value in actual test scenario, while average consistency error has been used in synthesizing, the test RPE is better than synthesized RPE.

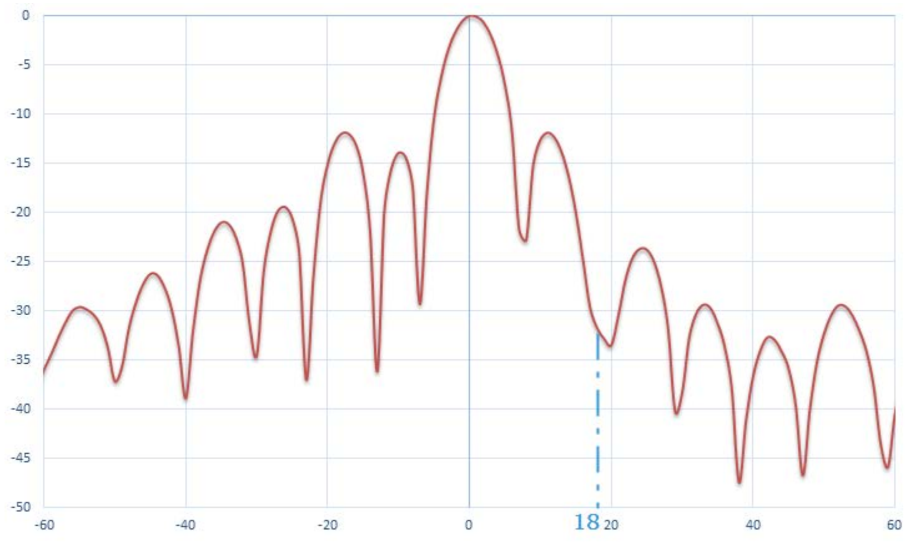


Figure B.5: Synthesized RPE using 200 MHz wide band signal with central frequency at 28 GHz with a null applied at 18° beside the main beam

From above simulations and lab tests, it can be summarized that the test result can achieve similar effect with that of simulation.

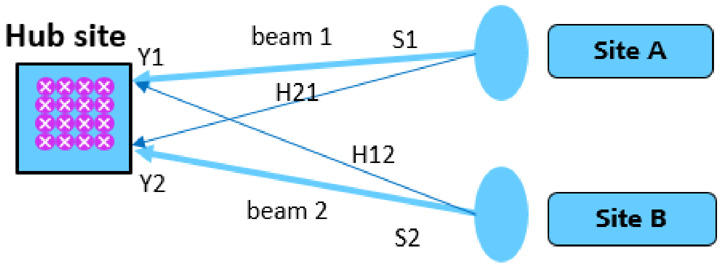
Beam nulling is an effective way to reduce the inter-sector and intra-sector interference. However, beam nulling is not a universal technology that can be used anywhere, to solve any interference problems. It is suggested to take consideration of collaboration of other interference mitigation technologies, including interference cancellation, frequency division, network planning, alternative polarization, etc., in actual implementation.

Annex C: Interference cancellation algorithms

This annex provides detailed information about the general algorithms of interference cancellation technology mentioned above in the present document.

As discussed in clause 5.4, there are two types of cancellation technologies.

The first type is from leaf sites to hub site, as shown in Figure C.1.



The meaning of the symbols are:

- S1 Transmitting signal from site A to hub site
- S2 Transmitting Signal from site B to hub site
- Y1 Receiving Signal from site A to hub site
- Y2 Receiving Signal from site B to hub site
- H12 Channel Transfer Function coefficient from site B to hub site after normalization
- H21 Channel Transfer Function coefficient from site A to hub site after normalization

Figure C.1: Interference cancellation from leaf sites to hub site

Then the channel matrix after normalization is:

$$\begin{bmatrix} 1 & H21 \\ H12 & 1 \end{bmatrix} \quad \text{(C.1)}$$

The relationship between receiving signal and transmitting signal is:

$$\begin{bmatrix} Y1 \\ Y2 \end{bmatrix} = \begin{bmatrix} 1 & H21 \\ H12 & 1 \end{bmatrix} \times \begin{bmatrix} S1 \\ S2 \end{bmatrix} \quad \text{(C.2)}$$

That is also:

$$Y1 = S1 + S2 \times H21 \quad \text{(C.3)}$$

$$Y2 = S2 + S1 \times H12 \quad \text{(C.4)}$$

Where:

Y1 and Y2 are the constants that are the already known receiving signals.

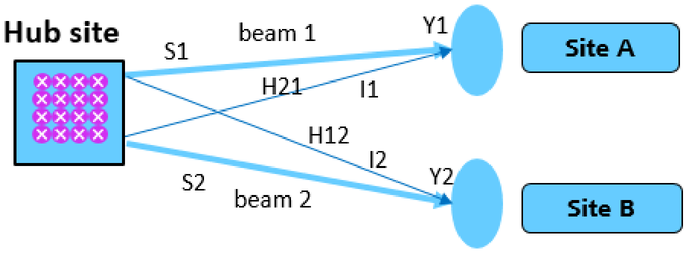
H21 and H12 can be calculated by channel estimation algorithm, and the normalization process also requires estimation of channel transfer function coefficient on beams.

Finally the variants S1 and S2 at the hub site would be:

$$S1 = (Y1 - Y2 \times H21) / (1 - H12 \times H21) \quad \text{(C.5)}$$

$$S2 = (Y2 - Y1 \times H12) / (1 - H21 \times H12) \quad \text{(C.6)}$$

The second type is from hub site to leaf sites, as shown in Figure C.2.



Similar to the first type, the meaning of the symbols are:

S1 Transmitting signal from hub site to site A
S2 Transmitting Signal from hub site to site B
Y1 Receiving Signal from hub site to site A
Y2 Receiving Signal from hub site to site B
I1 Interference from hub site to site A
I2 Interference from hub site to site B
H12 Channel Transfer Function coefficient from hub site to site A
H21 Channel Transfer Function coefficient from hub site to site B

Figure C.2: Interference cancellation from hub site to leaf sites

From the analysis above, Y1 and Y2 can be derived as:

$$Y1 = S1 + S2 \times H21 \quad (C.7)$$

$$Y2 = S2 + S1 \times H12 \quad (C.8)$$

Then the interference would be:

$$I1 = Y1 - S1 = S2 \times H21 \quad (C.9)$$

$$I2 = Y2 - S2 = S1 \times H12 \quad (C.10)$$

As H12 and H21 can be calculated by channel estimation algorithm, I1 and I2 would be calculated in the hub site. Hub site pre-codes the interference signals into the transmitting signals, by sending S1 -I1 = S1 - S2 × H21 to site A and sending S2 - I2 = S2 - S1 × H12 to site B. Finally site A and site B receive the original S1 and S2 respectively.

Channel matrix can be adjusted, by beamforming technology mentioned in clause 5.2 in the present document, as a result to better facilitate the interference cancellation.

Annex D:
RPE of active antenna used in simulations

RPE of the active antenna in hub site used in simulations in clause 7.5 are synthesized according to 3GPP TR 38.803 [i.5], and are shown below, from Figure D.1 to Figure D.5. The RPE are synthesized in single polarization and azimuth plane, in sector II (the blue sector in Figure 21). Figure D.1 from Figure D.4 show the separate RPE of individual sub-array connected to each leaf site from No.8 to No.15 in sector II, and Figure D.5 shows the whole RPE of active antenna covering sector II. It can be seen from the figures that, there are 7 nulls applied to each beam in this active antenna.

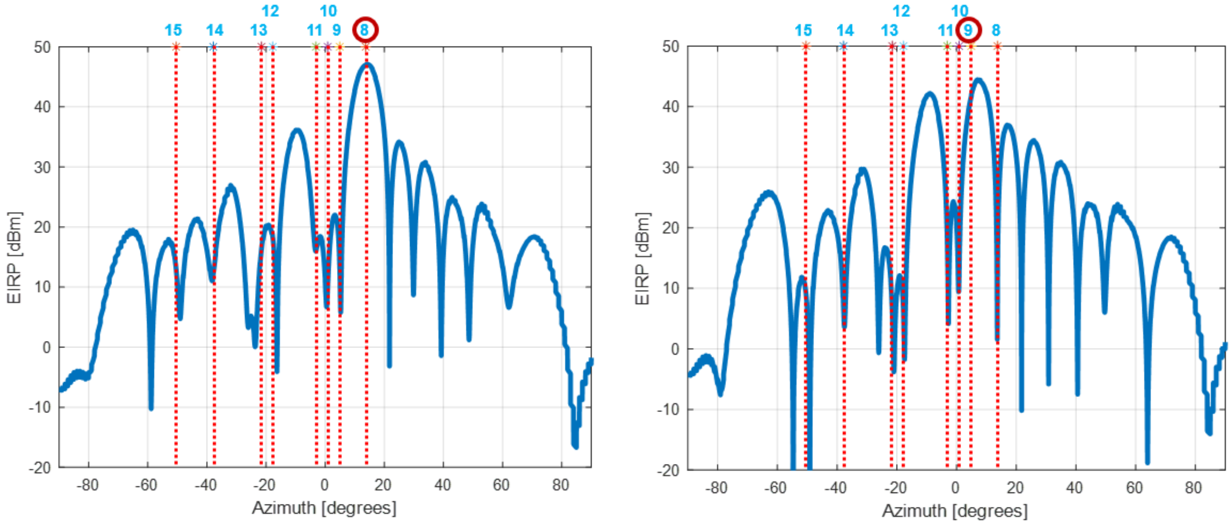


Figure D.1: RPE of sub-array connected to leaf site No.8 and 9

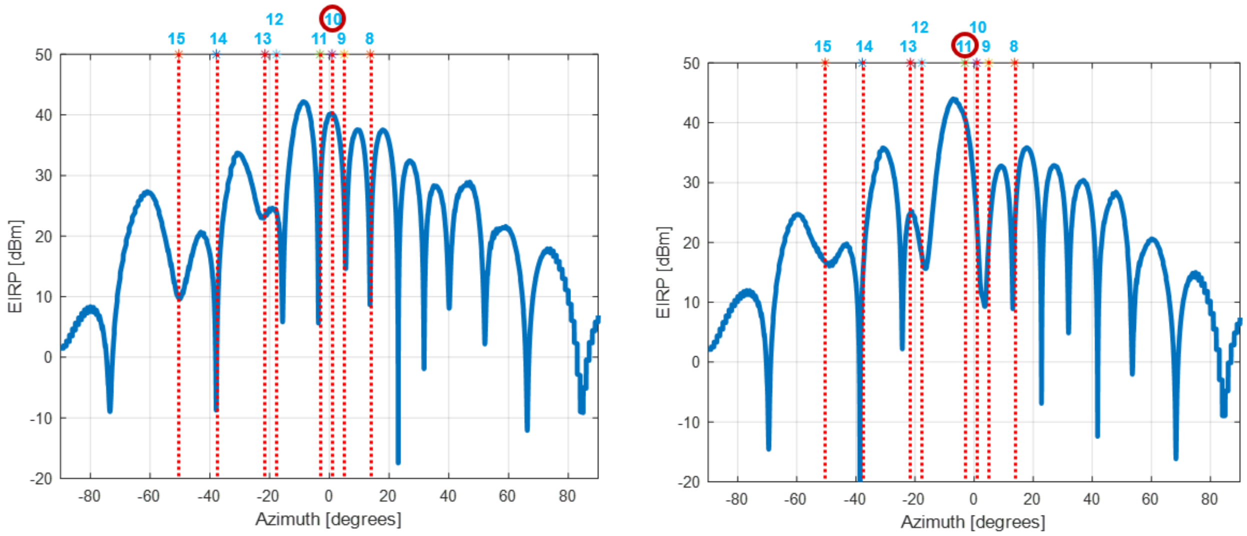


Figure D.2: RPE of sub-array connected to leaf site No.10 and 11

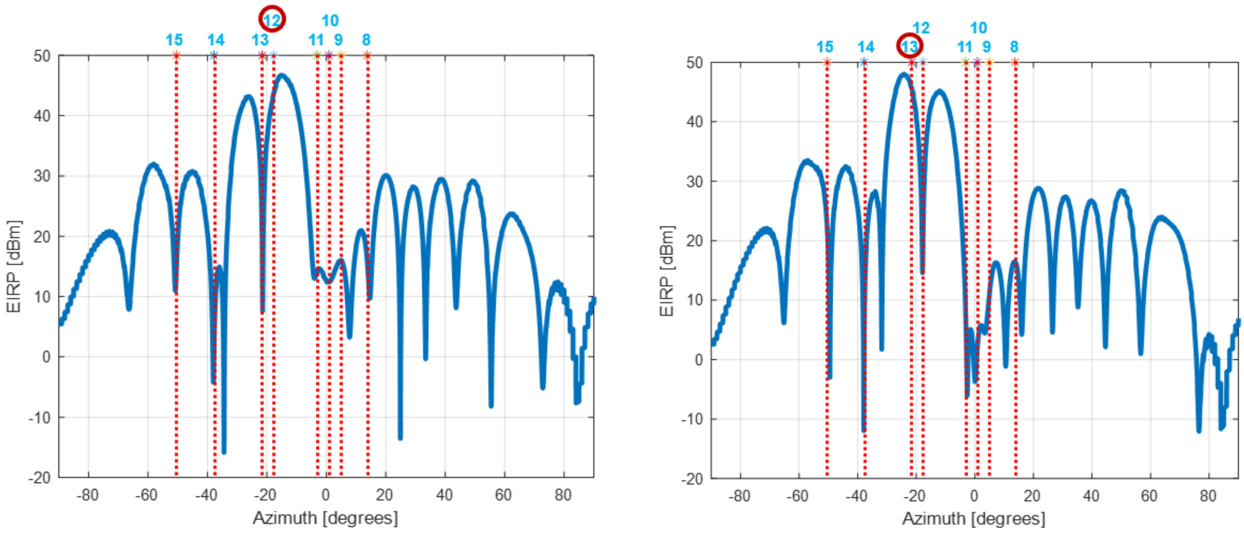


Figure D.3: RPE of sub-array connected to leaf site No.12 and 13

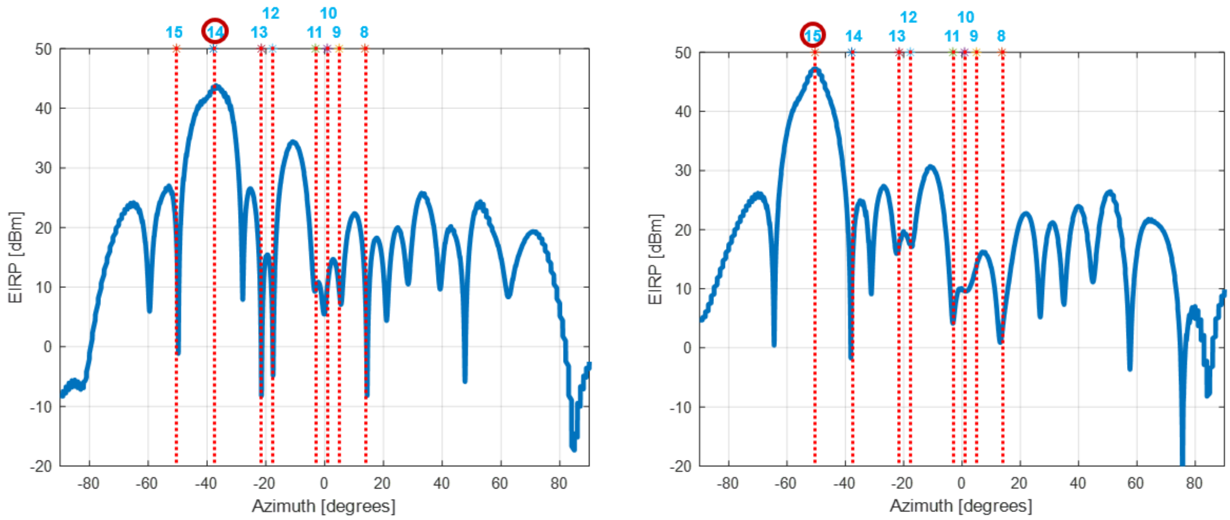


Figure D.4: RPE of sub-array connected to leaf site No.14 and 15

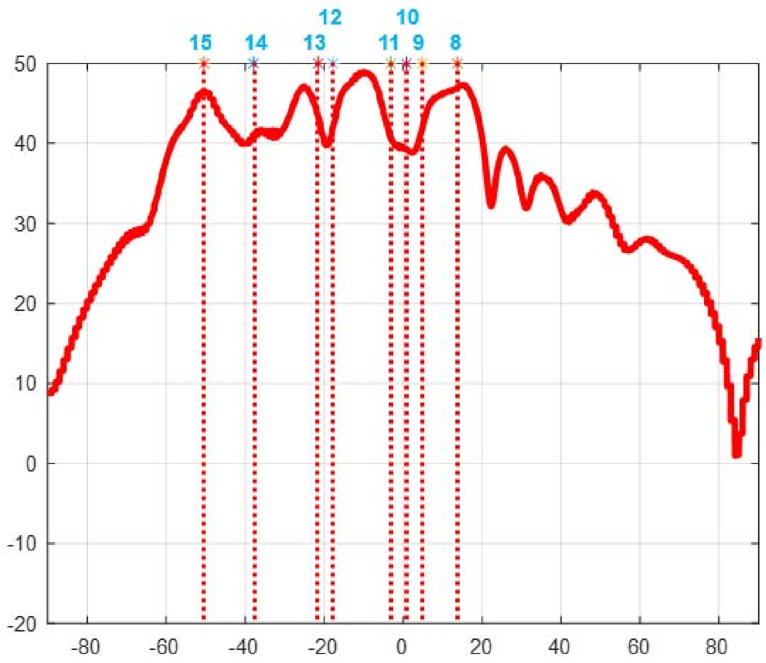


Figure D.5: Whole RPE of active antenna covering sector II

Note that from the diagrams above, it can be seen that, the RPE of active antenna in new PtMP structure is not the same as the addition of N point-to Point directive beams, which the condition is happening on the air when some P-P antennas, located in same tower /pole are pointing each one in its proper direction. Spatial emission is in principle more similar to the central station diagrams of the existing PmP structure which are covered in the same sector. Each leaf link in the new PtMP structure works correctly since the interference contributions from other links are nulled.

History

Document history		
V1.1.1	October 2020	Publication