



New KPI's for planning microwave and millimetre wave backhaul network

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

Modal verbs terminology

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Executive summary

The ever increasing 4G and 5G traffic demand has reached a level that MW/mmW wireless backhaul extra cost due to link over-engineering is not affordable any more in terms of spectrum resources (license fees), size of antennas to be deployed, products to be used and energy consumption.

The well-known link dimensioning approach adopted today is based on two KPIs: Committed Information Rate (CIR) and Peak Information Rate (PIR) with relevant target availability derived from legacy networks. This methodology is not considering the fact that 99 % of the backhaul traffic nowadays is data.

The present document defines a new KPI called Backhaul Traffic Availability (BTA) that is based on the statistical nature of Radio Access Network (RAN) data traffic and the statistical behaviour of wireless backhaul link capacity against propagation related fading (such as rain fading). BTA represents the probability that wireless backhaul link is not congesting RAN traffic.

The present deliverable provides network simulation results demonstrating that BTA levels above 99,7 % does not impact end user Quality of Experience. Such BTA target levels can easily be met by E-Band and BCA (Band and Carrier Aggregation) links with hop lengths much longer (almost double) than typical limits derived by link dimensioning approach used today.

Finally, the present document provides baseline for a new link dimensioning approach based on CIR, PIR and BTA, called three-check points planning method. This new approach allows more efficient spectrum utilization re-considering a less conservative definition of CIR (that is no longer calculated as percentage of PIR) and PIR targets, while using BTA to make sure that the link will be capable to deliver RAN traffic without impacting Quality of Experience.

This new methodology does not change the foundation of radio propagation, it does not require new features on MW/mmW equipment and it is not changing the way spectrum is used. It only needs a simple additional module in the link planning tool for BTA calculation.

Introduction

Mobile backhaul with Microwave (MW) radio links is dating back to early 90s of last century when Mobile Network Operators (MNOs) started deploying 2G networks for voice services. 2G backhaul was a simple E1 (2 Mbps) TDM interface that was transported over PDH MW links using one single static modulation. Therefore, MNOs started to plan backhaul links based on link outage targets (derived by Recommendation ITU-T G.827, [i.1]) that were mapping one to one with voice service outage.

Since those days MNOs have deployed 3G, 4G and now 5G Radio Access Networks (RAN) introducing data services on top of voice services: this took place with an exponential growth of backhaul capacity demand that is summarized within following picture (more details on 5G capacity demand can be found in [i.2]). In a nutshell, it has started with 2 Mbps for 2G, and with 5G launch there is a need for 2 Gbps (and beyond): this is 3 orders of magnitude capacity growth.

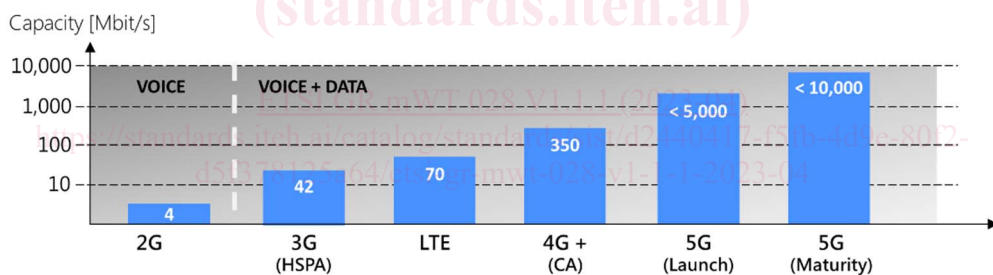


Figure 1: Backhaul capacity growth along RAN technology generations

In order to cope with an exponential backhaul capacity growth, MW technologies evolved introducing three key steps to make most efficient usage of spectrum resources:

- Adaptive Coding and Modulation (ACM): for increasing spectral efficiency without compromising on link outage.
- E-Band millimetre Wave (mmW) usage: for leveraging huge free spectrum on short hops.
- Band and Carrier Aggregation (BCA): for increasing E-Band applicability on longer hops without compromising on link outage.

All these MW and mmW technologies introduced a wide dynamic range of capacity and availability pairs on top of the simple TDM concept of link availability (outage) that was used for 2G. These new technologies have been deployed by MNOs worldwide using planning availability criteria and targets derived by TDM consolidated concepts. Generally speaking, large majority of MNOs adopted the following approach:

- link availability target was kept unchanged (4 to 5 nines typically) and a minimum target link capacity or committed information rate (CIR) was defined based on a variety of criteria;

- maximum link capacity or Peak Information Rate (PIR) target was defined based on RAN technology deployed using simple formulas (most famous ones come from NGMN [i.3]) and setting a "less conservative availability target" (4 nines, 3 nines, 2 nines) without strong rationales.

Regardless of which formulae and target availabilities MNOs choose to adopt, none of them can be considered a proper planning methodology because they are missing to take into account two key aspects:

- RAN traffic cannot be described using only two figures (minimum and maximum, translated into CIR and PIR); traffic demand is a continuous set of values (from min to max) with certain occurrence probabilities;
- MW/mmW backhaul link impact on RAN traffic demand cannot be described by two availability targets (those associated with CIR and PIR) because it depends on full set of capacity and availability pairs provided by ACM and BCA technologies.

The present document aims at defining a new planning methodology that will be based on the two key aspects listed above. As the established planning methodology is based on some KPIs (CIR, PIR and relevant availability targets) there is the need to define a new KPI in order to have a measurable parameter that can be calculated during link design phase and then monitored in the network.

Reasons triggering the need of a new planning methodology is that existing one can lead to:

- either a link over-engineering in case of too demanding availability targets (e.g. when setting 4 nines on PIR);
- or a link under-engineering in case of reduced capacity targets (e.g. a PIR that does not suit RAN traffic peak burstiness).

This fact is true since 3G era when MNOs started delivering data services. Nowadays with 4G and 5G traffic demand levels, the Total Cost of Ownership (TCO) impact due to link over-engineering is becoming bigger and bigger in terms of spectrum resources (license fees), size of antennas to be deployed, products to be used, etc. In other words, MNOs deserve a more suitable planning methodology in order to optimize MW/mmW backhaul links TCO.

At the same time, this new planning methodology will ensure MNOs that MW/mmW backhaul links are properly serving RAN traffic without impacting network performances, overall network KPIs and finally the User Experience (most important aspect).

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1 Scope

The present document is aiming at the definition of new KPI's for planning microwave and millimetre wave backhaul networks. Identification of new KPI's should take into account the evolution of wireless backhaul:

- more challenging requirements coming from 5G deployment;
- new technologies aiming at more efficient interference mitigation and cancellation;
- increase of use of spectrum in the millimetre wave range, both stand-alone and aggregated (BCA);
- different typologies and mix of services transported.

User Experience is the key driver for backhaul dimensioning considered in the present document. Studies, carried out to produce the present document, have considered RAN traffic characteristics (both network measures and full (propagation, interference, multi users, scheduling and protocols) RAN simulations) in conjunction with backhaul link behaviour against propagation related fading (e.g. rain fading, multipath fading, etc.), with the aim to reach the most efficient backhaul spectrum usage and reduced Total Cost of Ownership (TCO).

The present document focuses primarily on "single backhaul link" (carrying one or multiple RAN site(s) traffic) that is baseline for MW/mmW planning. A few preliminary considerations on link daisy chains (legacy MW topology), hubs & spoke (on-going topology trend due to increasing fibre penetration) and more general geographic area approaches (i.e. clusters of hubs) can be found in annex A.

The present document considers RAN downlink traffic since it is more demanding than uplink traffic, thus becoming the backhaul link dimensioning constraint in case of FDD symmetric spectrum resources allocation (standard approach for all MW and mmW bands used for mobile backhaul today).

The present document is considering links already deployed and links that will be deployed using consolidated MW/mmW technology (such as ACM and BCA). However in the present document the reader will also find some general considerations on emerging MW/mmW technology evolutions.

The present document also provides an analysis of impacts and dependencies of the new KPI's on:

- network planning and monitoring (across entire link life cycle in a network);
- equipment standards (to spot if there are impacts or dependencies);
- spectrum regulations and licensing (to spot if there are impacts or dependencies).

Finally, it is also worth mentioning that Fronthaul (definition in 3GPP TR 38.801 [i.4]) is out of the present document scope, while mid-haul can be considered included in the scope of the present document because it has capacity & latency requirements very similar with backhaul ones. Regarding backhaul link, the present document focus is on propagation related fading and it does not consider end users experience impacts due to any other backhaul link impairments such as equipment failures, energy outage and network operations.

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] Recommendation ITU-T G.827 (September 2003): "Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths".
- [i.2] ETSI White Paper No. 25 (February 2018): "Microwave and Millimetre-wave for 5G Transport".
- [i.3] NGMN 0.4.2 FINAL (July 2011): "Guidelines for LTE Backhaul Traffic Estimation".
- [i.4] 3GPP TR 38.801 (V14.0.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on new radio access technology: Radio access architecture and interfaces (Release 14)".
- [i.5] Recommendation ITU-R P.530-18 (September 2021): "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".
- [i.6] Recommendation ITU-R P.837-7 (June 2017): "Characteristics of precipitation for propagation modelling".
- [i.7] ETSI GR mWT 016 (V1.1.1): "Applications and use cases of Software Defined Networking (SDN) as related to microwave and millimetre wave transmission".
- [i.8] ETSI EN 302 217-1 (all parts): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas".
- [i.9] Recommendation ITU-R F.1703-0 (2005): "Availability objectives for real digital fixed wireless links used in 27500 km hypothetical reference paths and connections".
- [i.10] Recommendation ITU-R F.2113-0 (January 2018): "Error performance and availability objectives and requirements for real point-to-point packet-based radio links".
- [i.11] ETSI TS 138 300: "5G; NR; Overall description; Stage-2 (3GPP TS 38.300 Release 15)".
- [i.12] ETSI TR 138 901 (V15.0.0): "5G; Study on channel model for frequencies from 0.5 to 100 GHz (3GPP TR 38.901 version 15.0.0 Release 15)".
- [i.13] 3GPP TR 38.838 (V17.0.0): "Study on XR (Extended Reality) Evaluations for NR".
- [i.14] 3GPP TR 36.814 (V9.2.0): "Further advancements for E-UTRA physical layer aspects".
- [i.15] 3GPP TR 36.873 (V12.7.0): "Study on 3D channel model for LTE".
- [i.16] Recommendation ITU-T P.1203 (October 2017): "Parametric bitstream-based quality assessment of progressive download and adaptive audiovisual streaming services over reliable transport".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

dimensioning (a link): activity carried out by MNO to calculate link system gain needed to meet all link capacity requirements

NOTE: Along the present document (link) planning or design is used as synonymous of (link) dimensioning

E1: European format for digital transmission of one PCM signal 2 048 kbit/s

end user experience (quality of experience): service quality perceived by a human being using a mobile terminal

mode: combination of a modulation order and a Forward Error Correction (FEC) coding scheme that a link can operate

propagation related fading: any possible fading due to propagation phenomena (such as rain or multipath) considered in Recommendation ITU-R P.530-18 [i.5]

3.2 Symbols

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

C_i	Link capacity value corresponding to a given link mode ($i=0,1,\dots,N$)
$P_o(C_i)$	Outage probability corresponding to a given link mode ($i=0,1,\dots,N$)

3.3 Abbreviations

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

2G	2 nd Generation Mobile Networks
3G	3 rd Generation Mobile Networks
4G	4 th Generation Mobile Networks
5G NR	5G New Radio
5G	5 th Generation Mobile Networks
ACM	Adaptive Coding and Modulation
BCA	Band and Carrier Aggregation
BTA	Backhaul Traffic Availability
CA	Carrier Aggregation
CDF	Cumulative Distribution Function
CG	Cloud Gaming
CIR	Committed Information Rate
DL	Down Link
E2E	End to End
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FTP	File Transfer Protocol
FWA	Fixed Wireless Access
GBR	Guaranteed Bit Rate
gNB	5G Node B
HD	High Definition
IP	Internet Protocol
KPI	Key Performance Indicator
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
mmW	millimetre Wave
MNO	Mobile Network Operator
MU	Multiple Users

MW	MicroWave
NGMN	Next Generation Mobile Networks alliance
NMS	Network Management System
OSI	Open Systems Interconnection
PDB	Packet Delay Budget
PDF	Probability Density Function
PDH	Plesiochronous Digital Hierarchy
PIR	Peak Information Rate
PM	Performance Monitoring
POP	Point Of Presence
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RBS	Radio Base Station
RS	Radio Site
SDN	Software Defined Network
SLA	Service Level Agreement
SU	Single User
SyncE	Synchronous Ethernet
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDM	Time Division Multiplex
UE	User Equipment
UL	Up Link
uR	ultra-Reliable
VR	Virtual Reality
WCDMA	Wide band Code Division Multiple Access
XPIC	Cross Polar Interference Canceller
XR	eXtended Reality

4 RAN traffic and MW/mmW backhaul

4.1 Statistical approach baseline

The present clause provides the mathematical baseline used to prepare the present document by defining:

- RAN traffic as a statistical random variable (T) determined by several factors such as service types, end users' number, end users' device performances, end users' geo-distribution across cell coverage, Radio Access network Technologies (RATs) deployed, radio access network design in terms of coverage, interference, etc.;
- MW/mmW backhaul link capacity as a statistical random variable (C) determined by rain fading and further possible propagation impairments (e.g. multipath fading, etc.), as per consolidated Recommendation ITU-R P.530-18 [i.5];
- a mathematical description of the relationship between these two statistical variables (RAN traffic and MW/mmW backhaul link capacity).

4.2 RAN traffic: behaviour and performances

RAN traffic generated by a single RAN cell (sector) with a single RAT is determined by several factors such as:

- end users' number served by the cell (this is continuously changing since it is a mobile network);
- end user's geo-distribution across cell coverage (given a certain number of users, overall cell traffic depends on whether users are under good or bad propagation conditions);

- end users' habits and services (traffic volume and traffic patterns changes a lot if users are doing web browsing on public transportation or using FWA service at home watching 4k videos);
- radio access network design in terms of coverage and interference (changing with RAT configurations and RAT features like SU-MIMO, MU-MIMO, CA, etc.);
- RAT parameters setting (changing continuously with optimization algorithms in place nowadays);
- end users' device performances (e.g. 4G/5G User Equipment Category 1, 2, ... to 26, etc.) that can leverage existing network resources to a certain level;
- etc.

It is worth noting, in the present document, that **RAN traffic is considered the amount of throughput potentially generated by a certain configuration of the radio access network** (in terms of the features specified above) **without taking into account possible bottlenecks imposed by the backhaul layer**. This definition, that dissociates the behaviour of the backhaul links from the actual traffic requests characterizing (in a statistical sense) the peculiar radio access scenario, will allow defining a new planning method for MW/mmWave backhaul systems that is fully oriented to the real End Users Experience.

All the above variables are impacting RAN traffic generated also in the simplest considered scenario (single RAN cell with a single RAT) that can only be described as a statistical random variable.

When considering the traffic generated by one RAN site, typically composed of 3 cells (sectors) and a combination of some RAT layers (4G + 5G across multiple bands), it can only be described with a statistical variable.

Then, when considering traffic generated by a certain number of RAN sites, once again it can only be described with a statistical variable.

By observing this statistical variable in a live network for a certain period of time, the resulting traffic pattern looks similar to the example shown in Figure 2: there is huge difference between minimum (low traffic hours) and maximum (busy hours traffic) and there is a certain periodicity along days and weeks.

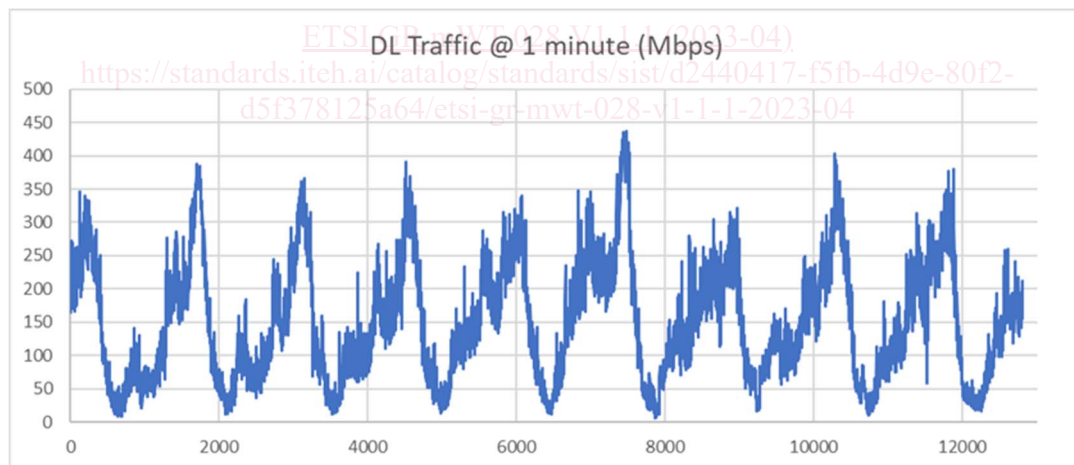


Figure 2: RAN traffic pattern example during 10 days

Traffic patterns are completely different in the case of a 4G+5G RAN site (using 150 MHz spectrum overall) in dense urban areas or in the case of a 4G RAN site (using 20 MHz spectrum) in rural areas, and this is quite obvious. What is less obvious is that different RAN sites with same set of RAT layers and spectrum usage, even when deployed within the same urban area, can have completely different traffic patterns due to the different number of users served during different time of the day. Moreover, even observing the same RAN site during 7 consecutive days and overlapping traffic patterns along the 24 hours, the typical outcome is very different daily patterns as depicted in Figure 3.

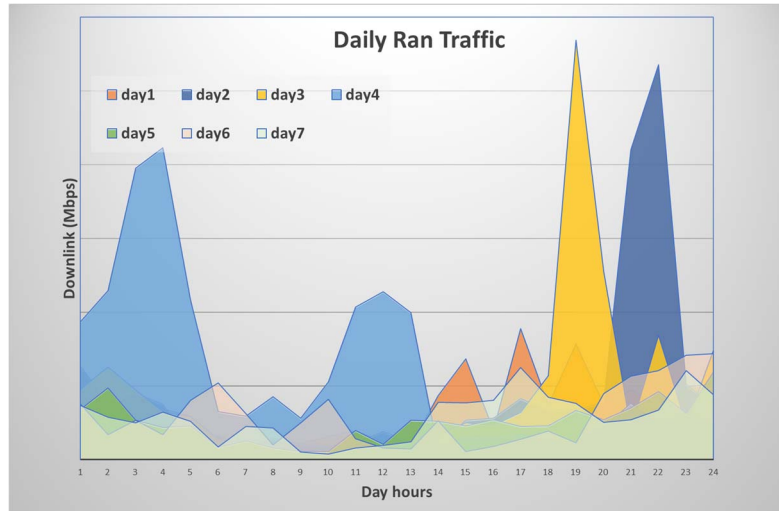


Figure 3: RAN site daily traffic patterns for 7 consecutive days

Therefore, it is not possible describing RAN traffic behaviour with simple formulae, see [i.3], that calculate some few theoretical RAN performance figures (peak, average, etc.) based on the number and type of RAT layers deployed. The only viable approach is to consider RAN traffic as a statistical random variable (T) that can be described by its own Probability Density Function (PDF) or Cumulative Distribution Function (CDF) as depicted in Figure 4. The traffic PDF shape for a given RAN site will change from one day to another and, of course, it will shift to the right along years while the overall end users throughput grows (see Figure 4 b).

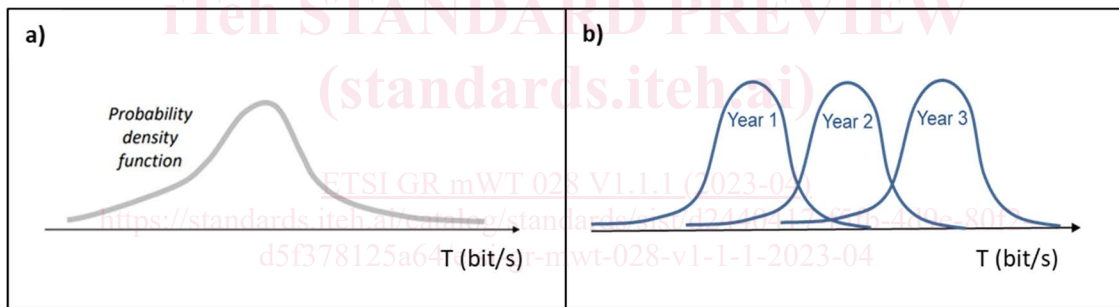


Figure 4: RAN site traffic PDF ($\text{RAN}_{\text{PDF}}(T)$) (a) and its evolution along years with traffic growth (b)

From previous considerations (see Figure 2 and Figure 3), it is evident that RAN traffic (T) is not a stationary process, in the sense that PDF, average, variance, etc. change over time. Therefore, the first question link planners can have is the following: which PDF should be considered? The answer is the following: most appropriate PDF can be identified according to actual needs. If it is for link planning purposes, it might be useful considering worst case traffic PDF measured over the network for all RAN sites with same RAT set-up. If it is for link monitoring purposes, it might be useful considering daily traffic pattern envelope across multiple days (see Figure 3), considering max value at any time and then calculating PDF.

One final remark is that, the only PDF (CDF) curve is sufficient to provide the overall RAN traffic description as it represents the amount of bits per unit of time, with the associated occurrence probabilities, that should be delivered by the backhaul network including the MW/mmW backhaul link serving the RAN, along hours, days, weeks, months and years.

4.3 MW/mmW backhaul capacity: behaviour and performances

MW/mmW backhaul link capacity (C) behaviour is characterized by:

- a minimum link capacity (usually identified as CIR) that can be delivered even with very deep propagation related fading before the link goes on full outage (when connectivity is down - zero traffic delivered for few minutes in a year in this case);

- a maximum link capacity (usually identified as PIR) that can be provided in clear sky conditions for most of the time in a year (usually more than 364 days in a year);
- a set of intermediate link capacities that can be provided (by ACM and BCA technologies) in between clear sky and deep propagation related fading conditions, usually referred as graceful capacity degradation, lasting for few hours in a year- as depicted in Figure 5.

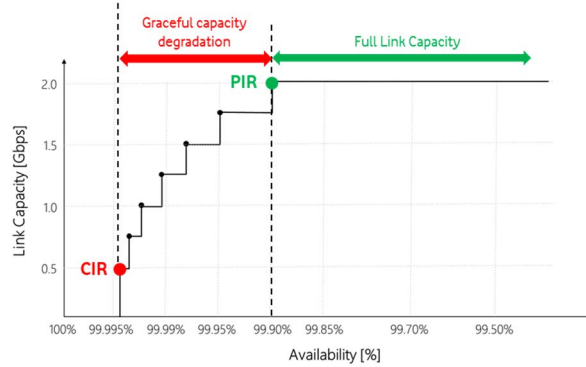


Figure 5: MW/mmW backhaul link capacity behaviour against propagation related fading events

Backhaul MW capacity provided by a link using ACM and BCA is a statistical random variable determined by:

- link design (system gain, bands, antennas, etc.);
- propagation impairments (mostly rain fading).

That does not have any periodicity, since capacity drops are taking place during some fading events randomly spread along the year, each one with different time duration and fading depth.

The time duration in which the backhaul link is providing a certain capacity level (c_i) is calculated as a probability of fading occurrence according to well established ITU-R prediction methods provided in Recommendation ITU-T P.530-18 [i.5]. This means that also MW/mmW link capacity performance can be described with a statistical random variable C that can only assume a discrete set of values $\{c_i\}_{i=1}^N$. Notice that each capacity value c_i can be associated with a certain outage probability $P_o(c_i)$ ($i = 1, 2, \dots, N$) as described in Figure 6. Accordingly the probability density function of MW/mmW backhaul link capacity C can be formulated in a continuous domain as (see Figure 6):

$$\Pr(C) = P_o(c_1) \cdot \delta(C) + \sum_{i=1}^{N-1} [P_o(c_{i+1}) - P_o(c_i)] \cdot \delta(C - c_i) + [1 - P_o(c_N)] \cdot \delta(C - c_N)$$

where $\delta(C)$ is the Dirac delta function.

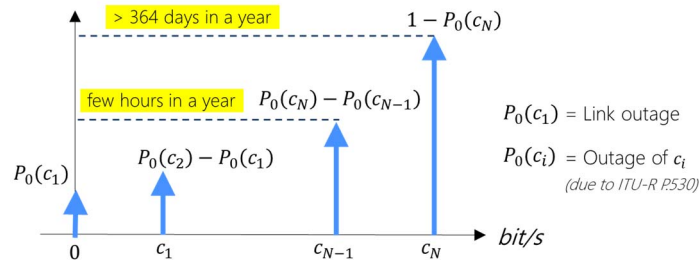


Figure 6: Statistical description of the MW/mmW backhaul link capacity

The set of pairs $(c_i, P_o(c_i))$ is what MW/mmW link planning tools calculate today with consolidated Recommendation ITU-R P.530-18 [i.5] prediction methods. MW/mmW planning methodologies adopted by MNOs today typically consider only a couple of these pairs, usually the two pairs $(c_1, P_o(c_1))$ and $(c_N, P_o(c_N))$.

4.4 RAN traffic and MW/mmW backhaul capacity relationship: mathematical description

In the previous clauses of clause 4, it has been described that both RAN traffic and MW/mmW backhaul capacity can be described with statistical random variables determined by:

- RAN network characteristics and users' behaviour for RAN traffic (T);
- propagation related fading events (or other possible adverse propagation conditions as outlined in Recommendation ITU-R P.530-18 [i.5]) for MW/mmW backhaul capacity (C).

Since there are no common factors determining RAN traffic and MW/mmW backhaul capacity, **these two random variables can be considered statistically independent** and therefore their joint probability density function is the product of the two probability density functions described previously in this clause. This is baseline to understand the mathematical relationship provided in this clause.

$$\Pr(T, C) = \text{RAN}_{PDF}(T) \cdot \left\{ P_o(c_1) \cdot \delta(C) + \sum_{i=1}^{N-1} [P_o(c_{i+1}) - P_o(c_i)] \cdot \delta(C - c_i) + [1 - P_o(c_N)] \cdot \delta(C - c_N) \right\}$$

$$\Pr(T, C) = P_o(c_1) \cdot \delta(C) \cdot \text{RAN}_{PDF}(T) + \sum_{i=1}^{N-1} [P_o(c_{i+1}) - P_o(c_i)] \cdot \delta(C - c_i) \cdot \text{RAN}_{PDF}(T) + [1 - P_o(c_N)] \cdot \delta(C - c_N) \cdot \text{RAN}_{PDF}(T)$$

Given a RAN site traffic PDF ($\text{RAN}_{PDF}(T)$) as per clause 4.2) and a MW/mmW backhaul link capacity PDF (as per clause 4.3) it is possible representing the joint probability density function formula $\Pr(T, C)$ as depicted in Figure 7, showing in a 3D representation:

- the set of N blue curves replicating the shape of RAN traffic PDF ($\text{RAN}_{PDF}(T)$);
- for different MW/mmW backhaul link capacities (0, c_1 , c_2 and c_N) weighted by relevant availabilities ($P_o(c_1)$, ($P_o(c_2) - P_o(c_1)$... and $1 - P_o(c_N)$).

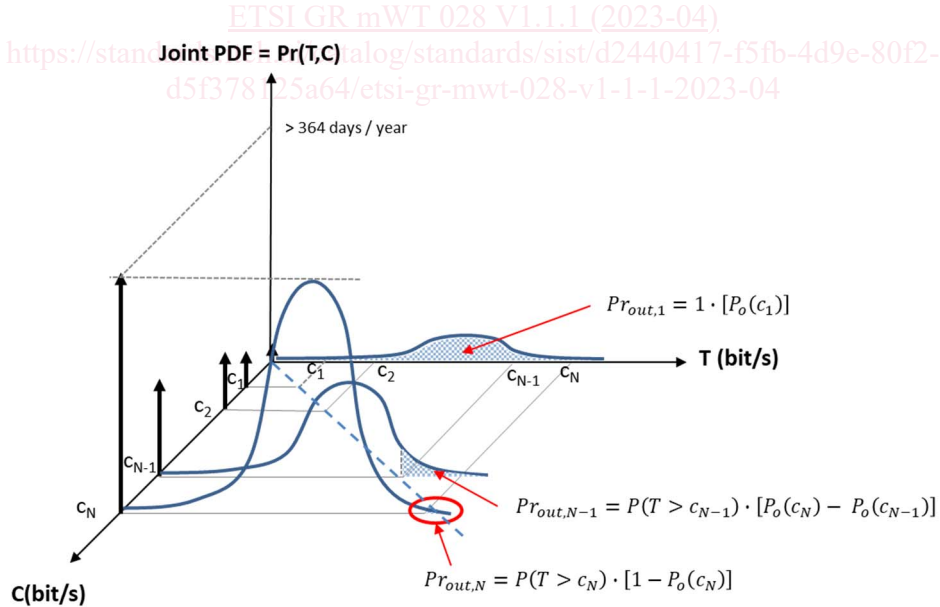


Figure 7: Joint probability density function and probability of RAN traffic exceeding backhaul capacity