



Practical Methods for Wireless Backhaul Planning with New KPIs

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Reference

DTR/ATTMTMmWT-0031

Keywords

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new KPIs, wireless

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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 Radio Fixed Services community represented by the ETSI ATTM TM_mWT Working Group has recently defined an innovative planning methodology for wireless backhaul links with the key benefit of enabling a cost-effective network design by reducing the required system margins in most microwave and millimetre-wave transport scenarios, compared to the current criteria, with negligible impact on the end-to-end Quality of Experience (QoE) of the Radio Access Network (RAN) users.

The novel planning methodology (that will be also referred to as the "New KPIs methodology" in the present document) reformulates the definition of two indicators already in use in current backhaul networks design - namely, the Peak Information Rate (PIR) and the Committed Information Rate (CIR) - and introduces the Backhaul Traffic Availability (BTA) as an innovative metric to assess the link performance by accounting for traffic-related information.

While on the one hand the BTA provides an effective representation of the probability that any backhaul link does not cause congestion in the aggregated RAN data flows, on the other hand it requires to operatively choose a specific traffic demand distribution to complete the assessment, thus possibly limiting the immediacy and in some cases the practical applicability of the New KPIs approach.

The present document takes up the challenge to overcome this hindrance by proposing practical methods to make the assessment of the BTA an immediate and straightforward process, once few baseline features of the target backhaul scenario are known. As a first key contribution, an experimentally validated analytical procedure for deriving the lower bound of the BTA of any given backhaul link with unknown traffic demand distribution - that can be readily employed for a conservative (i.e. worst-case) network planning - is disclosed. This method has the strategic advantage of relying on the only knowledge of the average and the peak values of the traffic demand envisioned for the link under investigation, thus making the choice of the complete statistical throughput distribution needed for computing the BTA metric a completely transparent process for the end user. Furthermore, the proposed procedure is conceived to be easily integrated into the software framework of the currently available backhaul planning tools, with the ultimate goal of further promoting and accelerating the adoption of the novel design paradigm in present and next generation transport networks.

As a second contribution, the present document describes a methodology for conducting measurement campaigns on live backhaul links with the aim of deriving a dataset of traffic demand distributions to be possibly used as reference statistics for the assessment of the BTA at least in a group of significant transport scenarios. In this context, the results of an experimental activity carried out during the preparation of the present document are also disclosed, serving as an example of how the proposed guidelines can be applied to build a proprietary database of backhaul traffic statistics to be employed in the network design process.

Finally, a comprehensive planning procedure for an illustrative point-to-point E-band link developed in accordance with the whole New KPIs paradigm is presented in order to provide a practical guide that can be adapted and scaled to more complex network scenarios and configurations.

Introduction

The projected traffic volumes driven by the proliferation of 5G and Beyond Radio Access Technologies (RATs) have raised serious concerns regarding the economic sustainability of transport infrastructures, particularly with respect to the Total Cost of Ownership (TCO). In this context, enhancing the cost efficiency of wireless networks by reducing the system margins often introduced by potentially over-engineered design methods has become imperative for telecom operators.

The Radio Fixed Services community represented by the ETSI ATTM TM_mWT Working Group has recently devoted significant efforts in this direction by finally defining an innovative planning methodology for wireless backhaul links in ETSI GR mWT 028 [i.1]. This new approach has been shown to lead to the key benefit of enabling a cost-effective network design by limiting the required system margins in most microwave and millimetre-wave transport scenarios, compared to the current criteria, with negligible impact on the end-to-end Quality of Experience (QoE) of the Radio Access Network (RAN) users.

The novel planning methodology (that will be also referred to in the following of the present document as the "New KPIs methodology") reformulates the definition of two indicators already in use in current backhaul networks design - namely, the Peak Information Rate (PIR) and the Committed Information Rate (CIR) - and introduces the Backhaul Traffic Availability (BTA) as an innovative metric to assess the link performance by accounting for traffic-related information. More specifically:

- The PIR is still defined as the maximum theoretical traffic that can be generated by the ensemble of the RAT layers transported over a given backhaul link, and it can be readily computed according to the well-established guidelines in, e.g., NGMN 0.4.2 [i.2] (figure 1 provides an overview of possible methods for the case of a single RAN site with three sectors). Unlike the current planning approach for backhaul networks, the New KPIs methodology does not associate the PIR with any availability requirement. Instead, it is dimensioned using a practical system-level criterion by adopting a fade margin of 5 dB to 10 dB to ensure stable link operation.

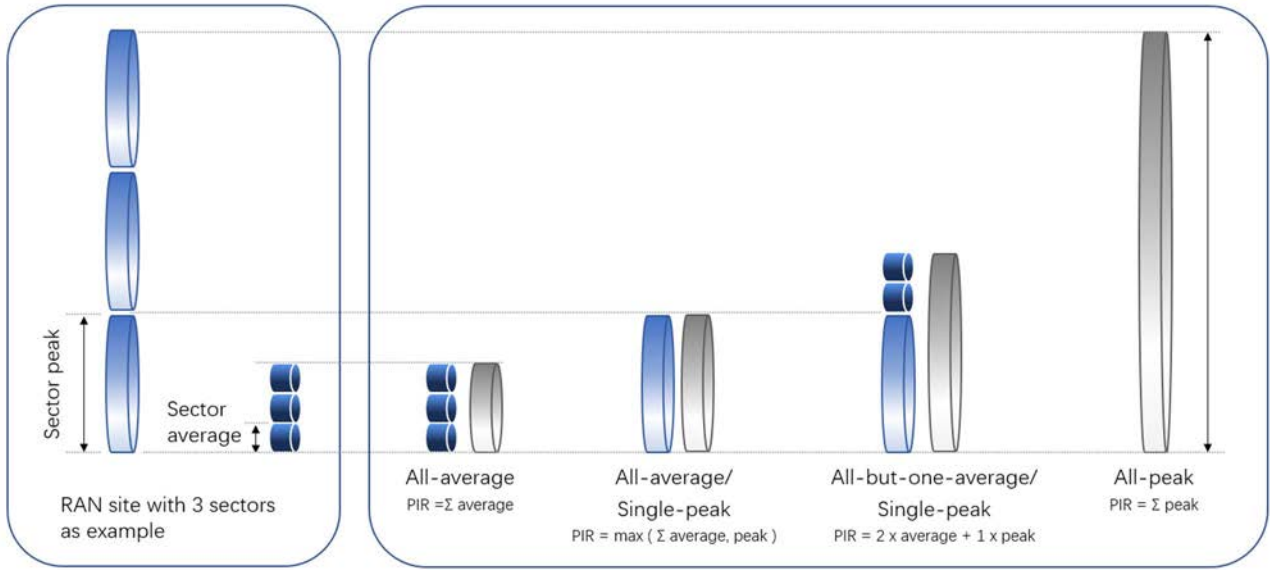


Figure 1: Overview of current methods for estimating the PIR for the case of a single RAN site with three sectors

- The CIR is recommended to be tailored to the minimum amount of capacity exclusively targeted to guarantee the survivability of the RAN and the essential and operator-specific top-priority services for the maximum time in a year (i.e. with an availability higher than 99,99 %).

While the amount of traffic required to meet the first objective can be easily calculated for the different RATs - since it corresponds to the necessary information flows to transfer the control, management and synchronization planes to the base stations - top-priority services are more difficult to quantify as they mostly depend on the specific propositions of Mobile Network Operators (MNOs) for their own customers and could comprise voice traffic (including emergency calls), Guaranteed Bit Rate (GBR) applications (e.g. mission-critical voice/video, real-time streams and 5G new use cases), as well as Service Level Agreement (SLA) data sessions. In any case, it is important to emphasize that the target CIR values to be employed in the novel wireless backhaul planning approach are highly dependent on the specific RAT scenarios, and they cannot be blindly estimated as a fixed percentage of the PIR across all cases. For example, in standalone 5G or mixed 4G and 5G sites baseline CIRs should be configured to fall between 1 % and 2 % of the PIR - significantly lower than the 10 % to 20 % range usually considered in current design methodologies (see ETSI GR mWT 028 [i.1] for a more detailed analysis on this matter).

- The BTA is defined as the probability that a given backhaul link is capable to deliver the entire aggregated traffic demand with no impacts on the RAN end-users QoE and, under a mathematical standpoint, it is expressed by the following weighted sum:

$$BTA = \sum_{i=1}^M P(C_{BH}^{(i-1)} < T \leq C_{BH}^{(i)}) \times \vartheta_{BH}^{(i)}, \quad (1)$$

where M is the total number of backhaul capacities that can be delivered, $\vartheta_{BH}^{(i)}$ represents the availability of the i th backhaul capacity $C_{BH}^{(i)}$ (with $C_{BH}^{(1)} < C_{BH}^{(2)} < \dots < C_{BH}^{(M)}$), and $P(C_{BH}^{(i-1)} < T \leq C_{BH}^{(i)})$ denotes the probability that the aggregated traffic demand T lies in the range between $C_{BH}^{(i-1)}$ and $C_{BH}^{(i)}$, being $C_{BH}^{(0)} = 0$ bit/s the link failure state. Terms $\vartheta_{BH}^{(i)}$ can be derived by applying the well-established guidelines and methods described in Recommendation ITU-R P.530-19 [i.4] and references therein, while probabilities $P(C_{BH}^{(i-1)} < T \leq C_{BH}^{(i)})$ can be easily computed from the cumulative distribution function $F_T(t)$ of the link aggregated traffic demand as (with $i = 1, 2, \dots, M$):

$$P(C_{BH}^{(i-1)} < T \leq C_{BH}^{(i)}) = F_T(C_{BH}^{(i)}) - F_T(C_{BH}^{(i-1)}) \quad (1a)$$

A massive number of system-level simulations accounting for different network conditions and aggregated RAN traffic demand profiles carried out in ETSI GR mWT 028 [i.1] have demonstrated that wireless backhaul links with BTA values above the 99,7 % to 99,9 % range do not introduce any perceivable degradation in the average end-to-end QoE performance of the RAN users even under highly demanding application scenarios.

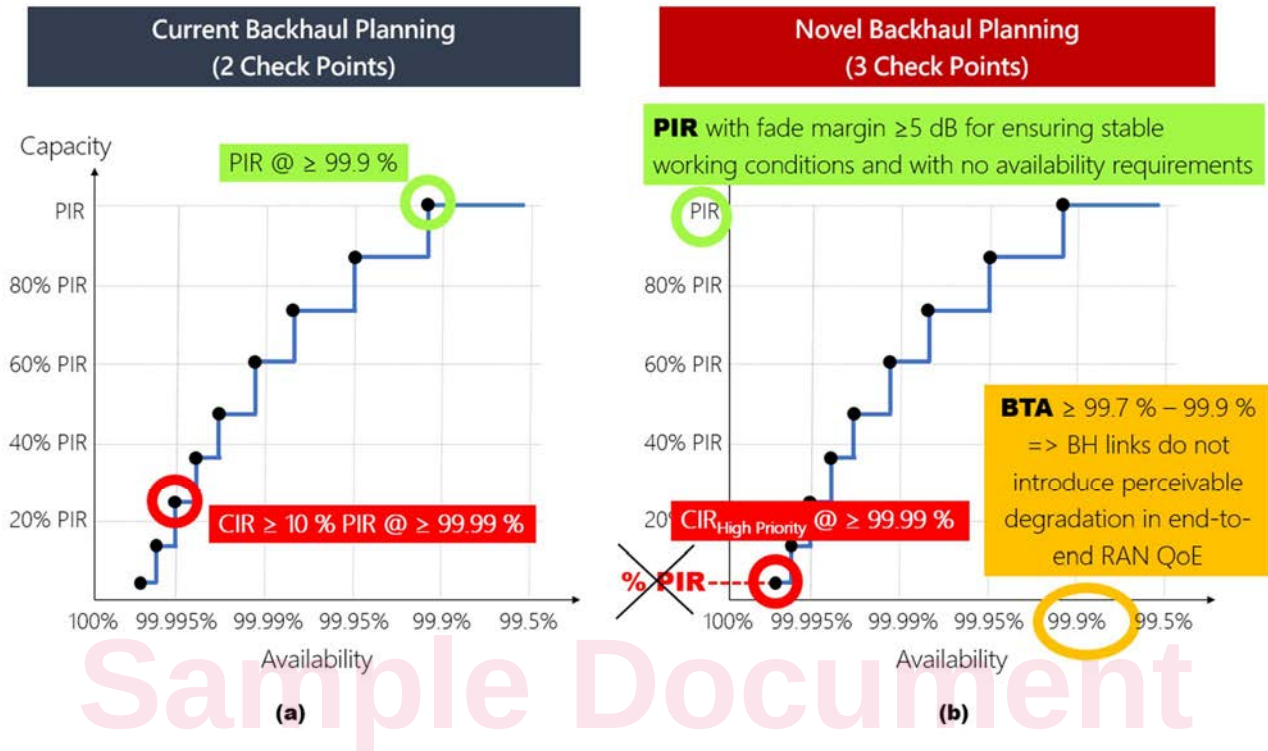


Figure 2: A comparison between current and novel planning methodologies for wireless backhaul links

The three check points characterizing the novel backhaul planning methodology described above are summarized in figure 2, that also presents a comparison with the current design approach.

On the one hand, the BTA offers an effective means of representing the probability that a given backhaul link does not cause congestion in the aggregated RAN data flows. On the other hand, though, it requires to operatively choose a specific traffic demand distribution to complete the assessment (i.e. for computing probabilities $P(C_{BH}^{(i-1)} < T \leq C_{BH}^{(i)})$ in equation (1)), thus possibly limiting the immediacy and in some cases the practical applicability of this approach, ultimately leading to a potential reluctance among MNOs to adopt the New KPIs methodology.

The present document takes up the challenge to overcome this hindrance by proposing practical methods for enabling a fast and straightforward assessment of the BTA, based solely on few baseline features of the target backhaul scenario. As a first key contribution, clause 4 discloses an experimentally validated analytical procedure for deriving the lower bound of the BTA of any given backhaul link on the basis of the sole knowledge of its average and peak expected aggregated traffic demands. The proposed approach offers the key benefit of leading to the derivation of a worst-case (i.e. minimum achievable) BTA value that does not depend on any specific assumption on the actual and complete traffic statistical distribution characterizing the link under inspection, and that can be readily employed for a conservative and effective network planning.

NOTE: It is remarked that, both in the last sentence and in similar contexts throughout the entire present document, the term "conservative" refers exclusively to the BTA evaluation. It does not extend to the overall New KPIs methodology, which is instead specifically designed to avoid introducing unnecessary system margins compared to current backhaul planning approaches.

As a second contribution, clause 5 describes a methodology for conducting measurement campaigns on live transport networks with the aim of generating a dataset of traffic demand distributions that can serve as reference statistics for the assessment of the BTA at least in a group of representative backhaul scenarios. In this context, the results of an experimental activity carried out during the preparation of the present document are also disclosed as a practical example of how to apply the proposed guidelines.

The use of the above-mentioned strategies for assessing the BTA is then exemplified in clause 6, that is entirely devoted to the description of a comprehensive planning procedure of a point-to-point link operating in E-band according to the whole New KPIs approach.

Finally, annex B presents a methodology targeted at a general assessment of the benefits, in terms of cost of ownership, of the New KPIs paradigm, with the ultimate goal of encouraging and accelerating its adoption in current and next-generation wireless backhaul networks.

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1 Scope

The present document has the goal of defining practical and effective methods for planning wireless backhaul links according to the novel approach detailed in ETSI GR mWT 028 [i.1]. One key area of investigation and contribution is the design of appropriate prediction models of the aggregated traffic demand statistics of any backhaul link as a function of few high-level and easy-to-know RAN-related behavioural features, such as the average and the peak values of the transported throughput, or the configuration of the various radio access technologies implemented in the connected sites. The derived prediction models are conceived with the goal of being easily embedded within the software framework of the currently available backhaul planning tools, thus pursuing the strategic benefit of making the choice of the link traffic demand distribution required for enabling the New KPIs methodology (namely, for computing the BTA metric) a completely transparent process for the end user.

In this context, the present document discloses an analytical procedure targeted at deriving a pessimistic estimation of the BTA of any backhaul link on the basis of the sole knowledge of the average and the peak values of its traffic demand, that could be used for a conservative and practical network planning. Secondly, the present document describes a methodology for conducting measurement campaigns on live transport networks and for processing the collected data in order to create a discrete set of reference throughput demand distributions to be used in the assessment of the BTA of any backhaul link, after a proper identification and classification of its main deployment features (e.g. number and type of transported radio access layers) and statistical properties.

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 may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

- [i.1] ETSI GR mWT 028 (V1.1.1): "New KPI's for planning microwave and millimetre wave backhaul network".
- [i.2] NGMN 0.4.2 FINAL (July 2011): "Guidelines for LTE Backhaul Traffic Estimation".
- [i.3] A. K. Gupta and S. Nadarajah: "Handbook of Beta Distribution and Its Applications", Boca Raton, FL, USA: CRC Press, 2004.
- [i.4] Recommendation ITU-R P.530-19 (09/2025): "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".
- [i.5] Recommendation ITU-R P.676-13 (08/2022): "Attenuation by atmospheric gases and related effects".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

peak (aggregated) traffic demand: maximum value of the aggregated traffic demand process experienced by a given backhaul link

3.2 Symbols

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

i, j, k, ℓ	generic indices
$z \in \mathcal{Z}$	z is an element of set $\mathcal{Z}$
BTA	Backhaul Traffic Availability
M	total number of capacities that can be delivered by a given backhaul link
$C_{BH}^{(i)}$	i th capacity that can be delivered by a given backhaul link (with $C_{BH}^{(1)} < C_{BH}^{(2)} < \dots < C_{BH}^{(M)}$)
$C_{BH}^{(0)}$	link failure state
$\vartheta_{BH}^{(i)}$	availability of the i th backhaul capacity $C_{BH}^{(i)}$
$P(\mathcal{O})$	probability that event $\mathcal{O}$ occurs
T	random variable representing the aggregated traffic demand of a given backhaul link
$F_X(x)$	cumulative distribution function of a generic random variable X , evaluated at the argument x
$f_X(x, \alpha, \beta)$	probability density function of a generic Beta-distributed random variable X with parameters α and β , evaluated at the argument x
α	first shape parameter of the Beta distribution
β	second shape parameter of the Beta distribution
$\Gamma(p)$	gamma function evaluated at the argument p
$F_X(x, \alpha, \beta)$	cumulative distribution function of a generic Beta-distributed random variable X with parameters α and β , evaluated at the argument x
$I(x, \alpha, \beta)$	regularized incomplete Beta function with parameters α and β , evaluated at the argument x
$E[X]$	expected value of a generic random variable X
e^x	exponential function evaluated at the argument x
$\int_a^b g(x)dx$	integral of a generic real-valued function $g(x)$ with respect to the real variable x on an interval $[a, b]$
t_{max}	maximum (or peak) value of the generic aggregated traffic demand T
$\mathcal{M}_f$	continuous subspace of the re-scaled Beta distributions family where parameters α and β are related according to equation (10)
f	normalized average traffic demand value

N	total number of possible values for the shape parameter α in the analytical procedure for deriving BTA lower bounds
α_n	n th possible value for the shape parameter α
$\mathcal{A}$	discrete set of N possible values for the shape parameter α
β_n	n th possible value for the shape parameter β
$\mathcal{S}$	discrete set that contains all the pairs (α_n, β_n) satisfying constraint (13) on the derivative of the corresponding cumulative distribution functions
ρ	first parameter used in the analytical procedure for deriving BTA lower bounds
η	second parameter used in the analytical procedure for deriving BTA lower bounds
$\frac{\partial g(x)}{\partial x}$	derivative of a generic function $g(x)$ with respect to variable x
$g(x) _{x=\bar{x}}$	value of a generic function $g(x)$ evaluated at $x = \bar{x}$
γ_n	n th BTA value
$\min(\mathcal{Z})$	minimum among all the real values contained in a generic discrete set $\mathcal{Z}$
$\{a_1, a_2, a_3\}$	discrete set with values a_1, a_2, a_3
$\{a_n\}_{n=1}^N$	discrete set with all values a_n for indices n from 1 to N
T_{max}	random variable representing the maximum values of the link input traffic observed with a given time granularity
T_{min}	random variable representing the minimum values of the link input traffic observed with a given time granularity
T_{ave}	random variable representing the average values of the link input traffic observed with a given time granularity
$F_T^{1s}(t)$	cumulative distribution function of the average link input traffic observed with a time granularity on the order of 1 second
Q	total number of bits transmitted over a backhaul link in a given time interval
S	number of seconds in a generic time interval
$E[T_{busy}]$	average throughput exchange (in bit/s) that is expected during busy hours over a given backhaul link
r_1	coefficient representing the portion of the day classified as "busy hours"
r_2	coefficient representing the anticipated traffic reduction during off-peak periods with respect to busy hours
r_3	coefficient expressing the ratio between the expected peak traffic t_{max} and the average traffic demand $E[T]$ for a given backhaul link
A_k	k th radio site of a generic backhaul network
J	total number of possible radio configurations utilized in a link planning example
$\varphi(j)$	metric value for the j th radio link configuration
$P_{Tx}^{max}(j)$	maximum transmit power (in dBm) of the radio equipment available in the j th radio link configuration
$G_{Tx}(j)$	transmit antenna gain (in dB) of the radio equipment available in the j th radio link configuration

$G_{Rx}(j)$	receive antenna gain (in dB) of the radio equipment available in the j th radio link configuration
$FM_{PIR}(j)$	PIR fade margin (in dB) guaranteed by the j th radio link configuration
$P_{Tx}^{PIR}(j)$	transmit power relative to the PIR (in dBm) of the radio equipment available in the j th radio link configuration
PL	free-space path loss (in dB) experienced over a given backhaul link
GL	attenuation due to atmospheric gases (in dB) experienced over a given backhaul link
$S_{Rx}^{PIR}(j)$	receiver sensitivity threshold relative to the PIR (in dBm) of the radio equipment available in the j th radio link configuration
$C_{BH,max}$	maximum capacity delivered by a given backhaul link
ω	coefficient expressing the ratio between the actual peak traffic value t_{max} and the maximum capacity $C_{BH,max}$ delivered by a given backhaul link
G_{tot}	overall antenna gain in dB (namely, including both the receive and the transmit side) of a given backhaul link
d	distance covered by a given backhaul link
$BTA_{\ell,d}(G_{tot})$	actual link BTA obtained for the ℓ th traffic time series and the link distance d , considering an overall antenna gain equal to G_{tot}
L_i	total number of time series included in the i th test dataset
K	cardinality of the set of pairs of parameters (ρ, η) used in the numerical analysis
(ρ_k, η_k)	k th choice of a pre-defined set of K pairs of parameters (ρ, η)
$LB_{\ell,d,k}(G_{tot})$	BTA lower bound obtained for the ℓ th traffic time series, the link distance d and the k th pair (ρ_k, η_k) to be used in constraint (13), considering an overall antenna gain equal to G_{tot}
$\varepsilon_{\ell,d,k}$	relative error between the BTA lower bound and the actual link BTA obtained for the ℓ th time series, the link distance d and the k th pair (ρ_k, η_k) to be used in constraint (13)
$\Delta_{\ell,d,k}$	excess gain in dB needed to achieve a BTA lower bound $LB_{\ell,d,k}(G_{tot})$ numerically equal to the actual link BTA $BTA_{\ell,d}(G_{tot})$, obtained for the ℓ th time series, the link distance d and the k th pair (ρ_k, η_k) to be used in constraint (13)
v_k	lower bound efficiency, defined as the percentage of cases in which the proposed analytical procedure employing the k th pair (ρ_k, η_k) in constraint (13) succeeds in generating actual BTA lower bounds
$\mathbf{1}(x)$	step function evaluated at the argument x
TCO	total cost of ownership of a target backhaul network when the traditional planning methodology is applied
I	number of resolvable intervals of the link lengths distribution of a target backhaul network
c_i	cost of the least expensive transport technology that can be employed to cover all the connection distances included in the i th interval while satisfying the target conditions of the traditional planning methodology
p_i	relative number of links in a target backhaul network with distances included in the i th interval
$TCO_{New\ KPIs}$	total cost of ownership of a target backhaul network when the New KPIs planning methodology is applied
$\tilde{c}_i$	cost of the least expensive transport technology that can be employed to cover all the connection distances included in the i th interval while satisfying the target conditions of the New KPIs planning methodology

$\mathcal{L}_n$	n th subset of links of a given backhaul network
C	generic aggregation node in a given backhaul network
ξ_k	target end-to-end BTA to be guaranteed for the traffic generated by a generic radio site A_k of a given backhaul network
$\overline{BTA}_n$	target BTA to be guaranteed over the n th link of a given backhaul network
R	number of radio sites in a generic backhaul network

3.3 Abbreviations

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

2G	2 nd Generation
3G	3 rd Generation
4G	4 th Generation
5G	5 th Generation
ACM	Adaptive Coding and Modulation
ATTM	Access, Terminals, Transmission and Multiplexing
BH	Backhaul
BTA	Backhaul Traffic Availability
CDF	Cumulative Distribution Function
CIR	Committed Information Rate
DL	Downlink
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FWA	Fixed Wireless Access
GBR	Guaranteed Bit Rate
KPI	Key Performance Indicator
LTE	Long Term Evolution
MIMO	Multiple-Input-Multiple-Output
MNO	Mobile Network Operator
mWT	millimetre Wave Transmission
PAR	Peak-to-Average Ratio
PIR	Peak Information Rate
QoE	Quality of Experience
RAN	Radio Access Network
RAT	Radio Access Technology
RTPC	Remote Transmit Power Control
SLA	Service Level Agreement
TCO	Total Cost of Ownership
TDD	Time Division Duplex
UL	Uplink

4 An analytical procedure for deriving BTA lower bounds

4.1 Overview

The aim of this clause is to present a quick and straightforward analytical procedure for deriving the lower bound of the BTA of any given backhaul link on the basis of the sole knowledge of its expected average and peak aggregated traffic demands. The proposed approach offers thus the key benefit of leading to the derivation of a worst-case (i.e. minimum achievable) BTA value that can be readily employed for a conservative and effective planning whenever an estimation of the complete statistical distribution of the expected link traffic demand is not available.

The disclosed analytical procedure builds upon the possibility to reliably capture the statistical model of the traffic demand of any transport link through a conveniently selected Beta probability distribution, as debated in [i.1]. An overview of the use of the Beta distributions family to model backhaul traffic demand dynamics is given in clause 4.2, while the method for deriving conservative BTA values is detailed in clause 4.3.

4.2 Modelling the aggregated traffic demand of backhaul links through Beta distributions

The Beta distribution is a family of parametric continuous probability distributions defined on the interval [0,1]. The analytical expressions of the probability density function

$$f_X(x, \alpha, \beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\Gamma(\alpha)\Gamma(\beta)}\Gamma(\alpha+\beta), \quad (2)$$

the cumulative distribution function

$$F_X(x, \alpha, \beta) = I(x, \alpha, \beta), \quad (3)$$

and the expected value

$$E[X] = \frac{\alpha}{\alpha + \beta} \quad (4)$$

of a generic Beta-distributed random variable X depend on the value of the two positive parameters α and β , being

$$\Gamma(p) = \int_0^\infty z^{p-1} e^{-z} dz \quad (5)$$

the gamma function, and

$$I(x, \alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \times \int_0^x z^{\alpha-1}(1-z)^{\beta-1} dz \quad (6)$$

the regularized incomplete Beta function with parameters α and β [i.3], with $x \in [0,1]$.

Previous studies conducted by the ETSI ATTM TM_mWT community [i.1] argue that the statistical behaviour of the random variable representing the traffic demand of any backhaul link can be accurately modelled by a properly re-scaled Beta distribution. This implies that, based on relations (2), (3), and (4), the probability density function, the cumulative distribution function and the expected value of any traffic demand variable T with maximum (peak) value t_{max} can be approximated as:

$$f_T(t, \alpha, \beta) = \frac{1}{t_{max}} \times f_X\left(\frac{t}{t_{max}}, \alpha, \beta\right) = \frac{t^{\alpha-1}(t_{max}-t)^{\beta-1}}{(t_{max})^{\alpha+\beta-1}\Gamma(\alpha)\Gamma(\beta)}\Gamma(\alpha+\beta), \quad (7)$$

$$F_T(t, \alpha, \beta) = I\left(\frac{t}{t_{max}}, \alpha, \beta\right), \quad (8)$$

and

$$E[T] = \frac{\alpha}{\alpha + \beta} t_{max}, \quad (9)$$

respectively, for a convenient choice of the shape parameters α and β , and with the independent variable $t \in [0, t_{max}]$.

NOTE 1: Throughout the present document, the traffic carried over any link at any given time instant is modelled as a random variable T characterized by a statistical distribution that is assumed to remain constant over time.

NOTE 2: Terms maximum and peak are used interchangeably within the present document when referring to traffic demand random variables.

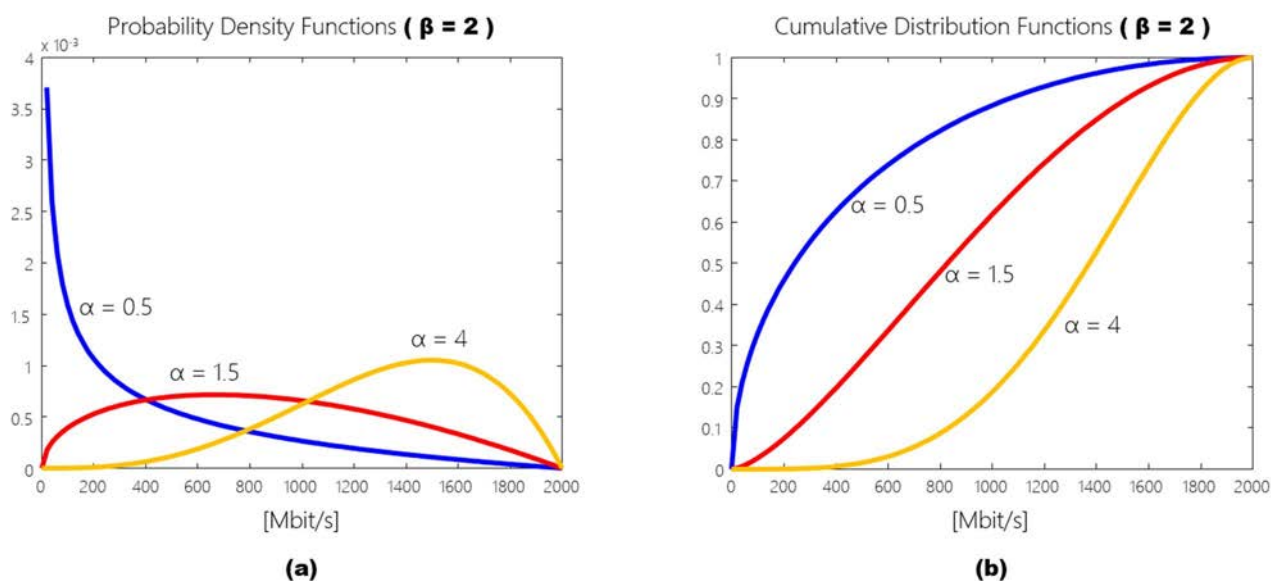


Figure 3: Illustrative probability density functions and cumulative distribution functions of Beta-distributed traffic demand random variables with fixed $\beta = 2$

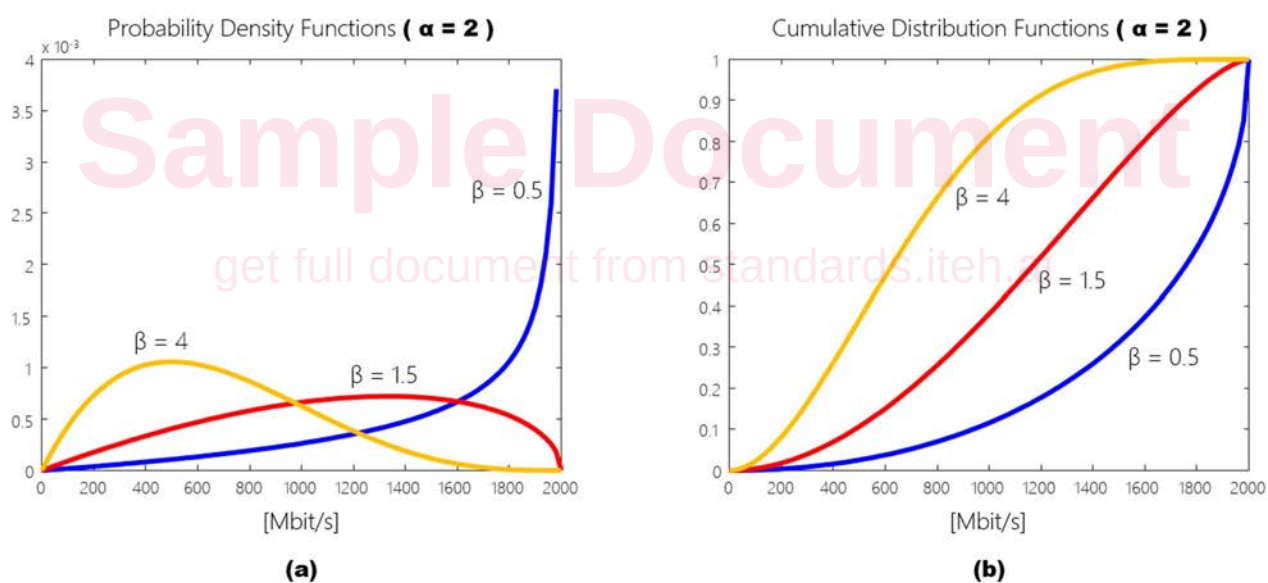


Figure 4: Illustrative probability density functions and cumulative distribution functions of Beta-distributed traffic demand random variables with fixed $\alpha = 2$