Oversubscription Dimensioning of Next-Generation PONs With Different Service Levels

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Overview

- Planning PONs using oversubscription concept and shows its applicability in the dimensioning of 1 Gb/s access
- With 2 types of users - basic (residential) and premium (business) with different service level requirements and activity patterns
- Show that only next-generation PON networks can reach a large number of users with acceptable service levels

Residential and Non-Residential Users

- 1 Gb/s downstream Internet access to both residential and business customers
- Residential customers use it as means to enhance their experience, given increasing devices
- Business services or wireless backhaul, require better service levels than conventional basic connections, in particular, low-latency and higher bandwidth guarantees

PONs

- PON is choice in medium and long term due to its speed and cost-effectiveness
- GPON and EPON are becoming widely spread in the access network, and their next-generations have been recently standardized
- OLT arbitrates access to the shared media thanks to a Dynamic Bandwidth Allocation algorithm which allocates transmission windows to users in a TDM-based sharing model
- Total bandwidth is shared between all users in a dynamic fashion, allowing assignment to only to active users as needed

Oversubscription Model

- Only few number of subscribers are simultaneously active allowing network designers apply oversubscription models and leverage statistical multiplexing gains
- Question is to what extent residential and business users can be mixed on the same PON while maintaining SLAs
- Show that only Next-Generation PON networks can reach a large number of users (split ratio 1:256) with acceptable service levels

Overview of TDM-PON Technologies

	GPON	XG-PON	TWDM-PON
ITU-T Standard	G.984	G.987	G.989
DL/UL Rate	2.5/1.25	10/2.5	40/10
(Gb/s)		10/10	80/20
Max. Split	1:64	1:128	1:256

- Both GPON and XG-PON networks use one wavelength for downstream and another one for upstream shared by TDM
- TWDM-PON stacks four or eight XG-PONs on different wavelengths (4 × 10G/2.5G, or 8 × 10G/2.5G).
- Both GPON and XG-PON may coexist on the same ODN, but the wavelength plans of TWDM-PON does not allow GPON or XG-PON users on the same ODN

Capacity Planning With Oversubscription For Single Class

- N refer to the maximum number of users physically attached to the same PON branch
- User activity is two-state Bernoulli processes, i.e. active with probability q or idle with probability $1-q$
- X refer to the random variable that considers the number of active users at a given random time, X follows a Binomial distribution $X \sim B(N, q)$
- B denote the rate observed per individual user in the PON branch, as follows:

  $B = \min\{C/X, B_{peak}\}$
- C is the total offered bandwidth capacity of each NG-PON technology B_{peak} is the maximum (peak) bandwidth rate provided to the users
- When all users are active ($X = N$), all users experience the minimum guaranteed bandwidth rate C/N, when k users are active C/k bandwidth is available

Important Metrics

Users and operators are interested in two metrics regarding bandwidth: average value *E(B)* perceived by active users and percentage of time *β* whereby a certain peak bandwidth B_{peak} is guaranteed

$$E(B) = \sum_{j=0}^{N} \min\left\{\frac{C}{j}, B_{peak}\right\} P(X = j)$$
$$= \sum_{j=0}^{N_{act}^{(max)}} B_{peak} \binom{N}{j} q^j (1-q)^{N-j}$$
$$+ \sum_{j=N_{act}^{(max)}}^{N} \frac{C}{j} \binom{N}{j} q^j (1-q)^{N-j}$$

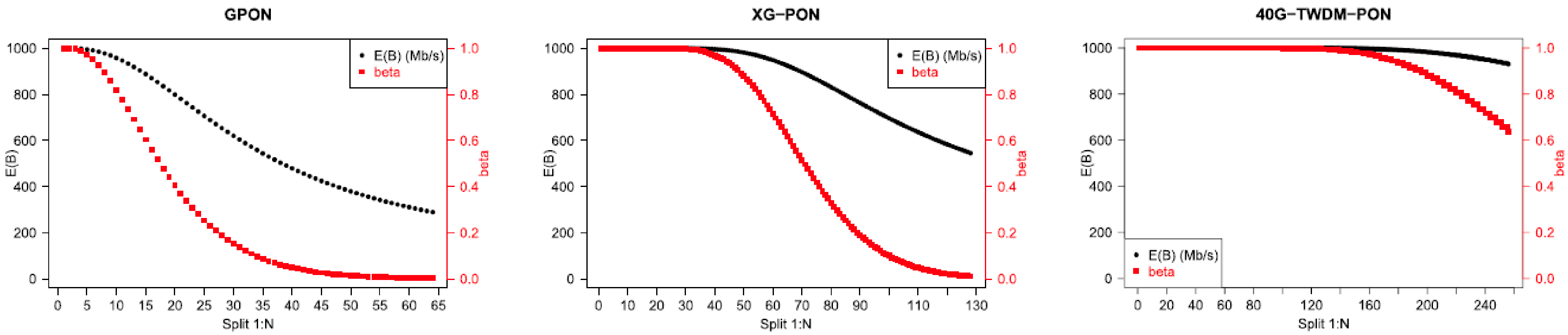
$$N_{act}^{(max)} = \left\lfloor \frac{C}{B_{peak}} \right\rfloor$$

$$\beta = P\left(X \leq \left\lfloor \frac{C}{B_{peak}} \right\rfloor\right)$$

BANDWIDTH COMPARISON BETWEEN THE MAIN PON TECHNOLOGIES: $E(B)$ AND β WHEN $B_{peak} = 1$ Gb/s

	Split 1:4	1:8	1:16	1:32	1:64	1:128	1:256
	$q = 15\%$						
GPON	998 Mb/s 99%	977 Mb/s 89%	870 Mb/s 56%	588 Mb/s 12%	289 Mb/s ~%	- -	- -
XG-PON	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s 99%	999 Mb/s 99%	929 Mb/s 63%	545 Mb/s 1%	- -
40G-TWDM	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s 99%	999 Mb/s 99%	929 Mb/s 63%
80G-TWDM	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s 99%	999 Mb/s 99%
	$q = 50\%$						
GPON	934 Mb/s 68%	665 Mb/s 14%	337 Mb/s ~0%	161 Mb/s ~0%	79 Mb/s ~0%	- -	- -
XG-PON	1000 Mb/s ~100%	1000 Mb/s ~100%	987 Mb/s 89%	645 Mb/s 2%	317 Mb/s ~0%	157 Mb/s ~0%	- -
40G-TWDM	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	987 Mb/s 89%	645 Mb/s 2%	317 Mb/s ~0%
80G-TWDM	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	1000 Mb/s ~100%	987 Mb/s 89%	645 Mb/s 2%

- When q = 15%, XG-PON significantly improves the results of GPON providing B_{peak} during a large percentage of time, allowing split ratios of up to 1:64.
- TWDM-PON provides at least 1 Gb/s during nearly 100% of the time for split ratios up to 1:128 and may even reach 1:256 with good performance (β = 63% and $E(B)$ = 929 Mb/s)
- When large user activity periods are expected, for instance q = 50%, only TWDM-PON can reach up to 64 users with a minimum of B_{peak} during 20% of the time.


GPON
E(B)
beta
E(B) (Mb/s)
Split 1:N
XG−PON
E(B)
beta
E(B) (Mb/s)
Split 1:N
40G−TWDM−PON
E(B)
beta
E(B) (Mb/s)
Split 1:N

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Modelling With 2 User Types

- Basic users that show low values of *q* and demand *Bpeak* only during a lo value of *β*, and (2) premium users that show large values of *q* and require *Bpeak* guaranteed during *βmin* = 100% of the time
- Maximum number of premium users *Np* is limited to: $Np = C/B_{peak}$
- Every pair *(Np, Nb)* where *Np* + *Nb* is a power of two, we need to compute the percentage of time where the basic users receive *Bpeak*:

$$P\left(X_b \le \left\lfloor \frac{C - B_{peak}X_p}{B_{peak}} \right\rfloor\right)$$
$$= \sum_{k=0}^{N_p} P\left(X_b \le \left\lfloor \frac{C - B_{peak}k}{B_{peak}} \right\rfloor \middle| X_p = k\right) P(X_p = k)$$

$$E(B_b) = \sum_{k=0}^{N_p} E(B_b | X_p = k) P(X_p = k), \quad X_p \sim B(N_p, q_p)$$

- TWDM-PON, the calculus can be reused from the XG-PON results, since TWDM-PON is in fact a stacking of four or eight XG-PONs on different wavelengths.
- For instance, 40G-TWDM-PON with split 1:128 is essentially a stacking of four XG-PONs on four different wavelenghts, thus allowing 32 users per lambda (4 × 32)
- 80G-TWDM-PON with split 1:256 gives the same numbers as XG-PON (1:32)
- Thus, at most ten business users can be located on the same wavelength of a TWDM-PON (i.e. 40 business total for 40G-TWDM-PON and 80 business users for 80G-TWDM-PON)

Bandwidth Comparison for Different Business/Residential Configurations in GPON, XG-PON and TWDM-PON

$E(B_b)$, β_b n_p	GPON 1:8	 1:16	 1:32	XG-PON 1:16 40G-TWDM 1:64 80G-TWDM 1:128	XG-PON 1:32 40G-TWDM 1:128 80G-TWDM 1:256	XG-PON 1:64 40G-TWDM 1:256 80G-TWDM 1:512*
$n_p = 0$	977, 89%	870, 56%	588, 12%	1000, ~100%	999, 99%	929, 63%
$n_p = 1$	947, 82%	795, 46%	499, 9%	1000, ~100%	998, 99%	913, 59%
$n_p = 2$	870, 72%	678, 36%	395, 6%	1000, ~100%	998, 98%	895, 54%
$n_p = 3$	-	-	-	1000, ~100%	997, 98%	875, 49%
$n_p = 5$	-	-	-	1000, ~100%	992, 96%	825, 40%
$n_p = 7$	-	-	-	999, ~100%	982, 92%	762, 31%
$n_p = 9$	-	-	-	998, ~100%	959, 86%	686, 23%
$n_p = 10$	-	-	-	994, 99%	941, 83%	643, 19%

Conclusion

- GPON provides good results for splits 1:8 and 1:16, but cannot meet the requirements for 1:32 and beyond. XG-PON is recommended for splits 1:32 and even 1:64 with a moderate number of premium Users
- 40G-TWDM-PON shows the same performance, but for splits 1:128 and 1:256, but 80G-TWDM-PON con go beyond these numbers and even reach 512 users.
- TWDM-PONs provide the best performance results and highest number of connected users.
- TWDM-PONs are cost-effective technologies in dense urban areas, where the average distance between the ONUs and the OLT is small and the Optical Distribution Network (ODN) can be shared by a large number of customers, not that much in rural areas