Evaluating the Applicability of Bandwidth Allocation Models for EON Slot Allocation

ILLUSTRATED TECHNICAL PAPER

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Abstract

This "**ILLUSTRATED TECHNICAL PAPER**" presents the slides describing the contents of the paper "Evaluating the Applicability of Bandwidth Allocation Models for EON Slot Allocation".

The talk was presented at **IEEE International Conference on Advanced Networks and Telecommunications Systems - IEEEANTS 2017**, 17 - 20 December 2017 at Bhubaneswar, Odisha, India.

The "illustrated technical paper format" is intended to complement, enrich and subsidize the technical paper content and contains slides, complementary text and additional and/or focused bibliographic references.

Index Terms

Elastic Optical Network, EON, Dynamic Resource Allocation, Bandwidth Allocation Model, BAM, Slot Allocation, MAM, RDM, ATCS.

1 PAPER ABSTRACT

Bandwidth Allocation Models (BAMs) configure and handle resource allocation (bandwidth, LSPs, fiber, slots) in networks in general (IP/MPLS/DS-TE, optical domain, other). In this paper, BAMs are considered for elastic optical networks slot allocation targeting an improvement in resource utilization. The paper focuses initially on proposing a BAM basic configuration parameter mapping suitable for elastic optical circuits. Following that, MAM, RDM and ATCS BAMs are applied for elastic optical networks resource

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allocation and the overall network resource utilization is evaluated. A set of simulation results and BAM "behaviors" are presented as a proof of concept to evaluate BAMs applicability for elastic optical network slot allocation. Authors argue that a slot allocation model for EON based on BAMs may improve utilization by dynamically managing the aggregated traffic profile.

2 PAPER SLIDES

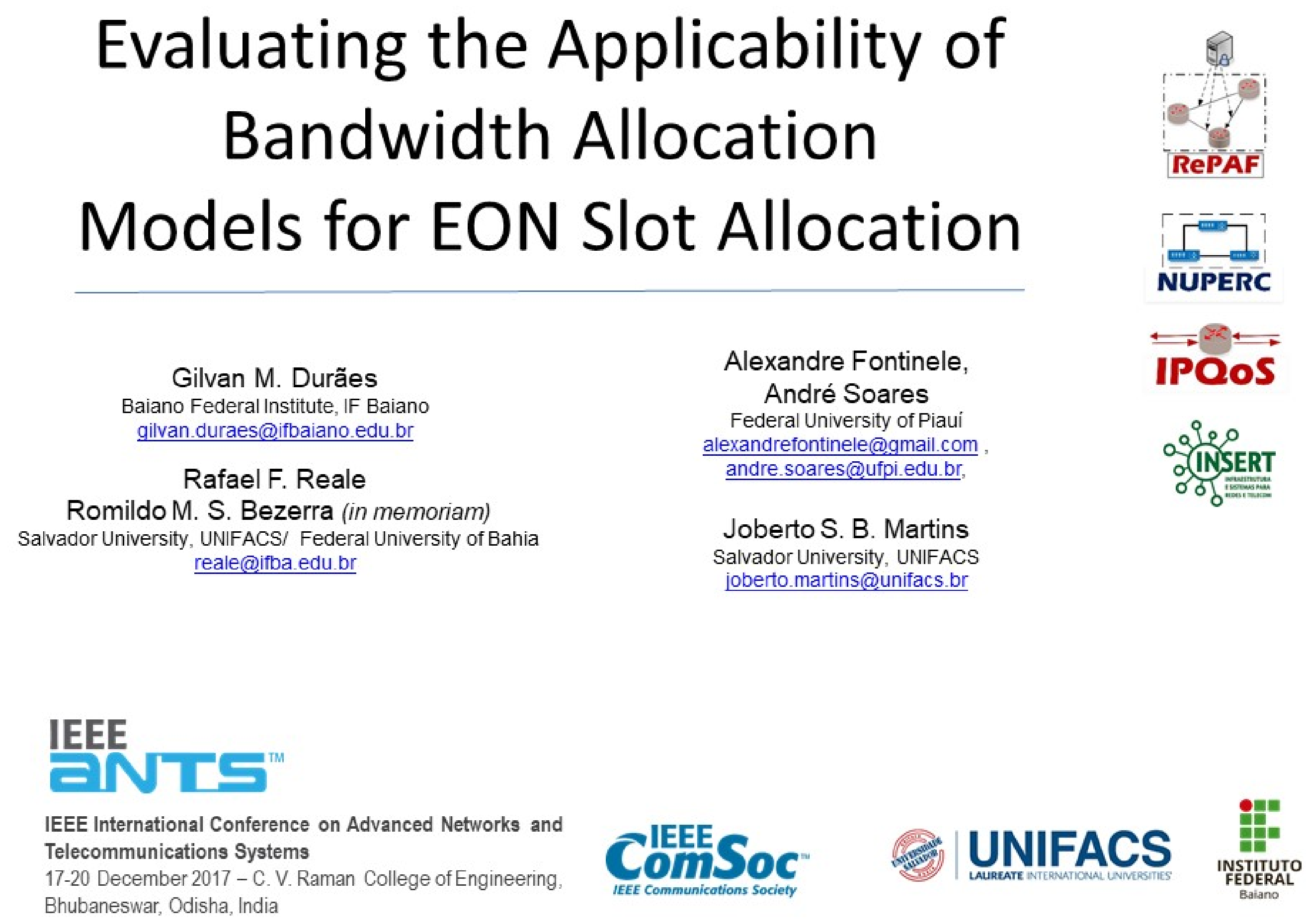

Fig. 1.

−− > **PAPER TEXT EXTRACT**:
This article presents **EON-BAM**, a novel approach that uses Bnadwidth Allocation Model (BAM) to dynamically allocate slots in a Elastic Optical Network (EON).
"Authors argue that a slot allocation model for EON based on BAMs may improve the optical network resource utilization by dynamically managing the BAM model used for distinct aggregated traffic profiles."

−− > **Paper to read:**

– The full paper text describing the EON-BAM management solution is **"Evaluating the Applicability of Bandwidth Allocation Models for EON Slot Allocation"** and is available at:
  ∗ IEEE Explorer: https://ieeexplore.ieee.org/document/8384163
  ∗ Reale at al. in [1] at Research Gate: https://www.researchgate.net/publication/320434478_Evaluating_the_Applicability_of_Bandwidth_Allocation_Models_for_EON_Slot_Allocation

$-- >$ **Complementary papers on BAM configuration, operation and management**:

- A summary of Bandwidth Allocation Models (BAMs) is presented in [2]
- A summary of BAM management switching alternatives is discussed and evaluated in [3]
- An overview (in Portuguese) of Bandwidth Allocation Models (BAMs) is presented in [4].

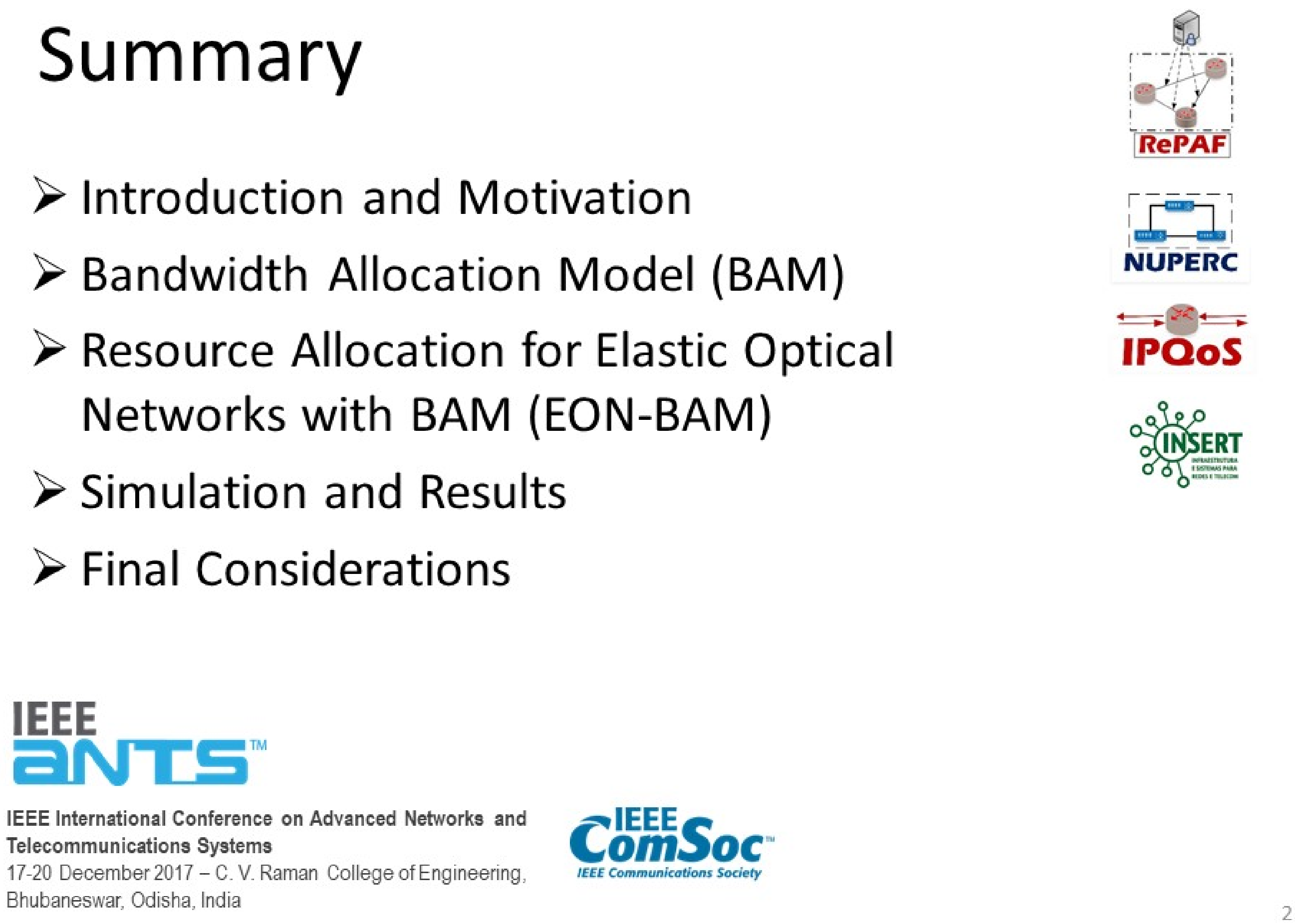

Fig. 2.

−− > **PAPER TEXT EXTRACT**:

"The paper [1] is organized as follows. Section II presents the related work; Section III presents a brief review and analysis of the most applied and referenced bandwidth allocation models (MAM, RDM, and ATCS - AllocTC-Sharing) that are considered for EON. Section IV proposes a mapping of bandwidth allocation model's characteristics for EON. Simulation results are presented in Section V as a proof of concept for evaluating the benefits of BAMs applicability in EON. Finally, the conclusions are presented in Section VI.".

−− > Papers to read:

- A tutorial on routing and spectrum allocation issues for elastic optical networks (EON) is available at [5].

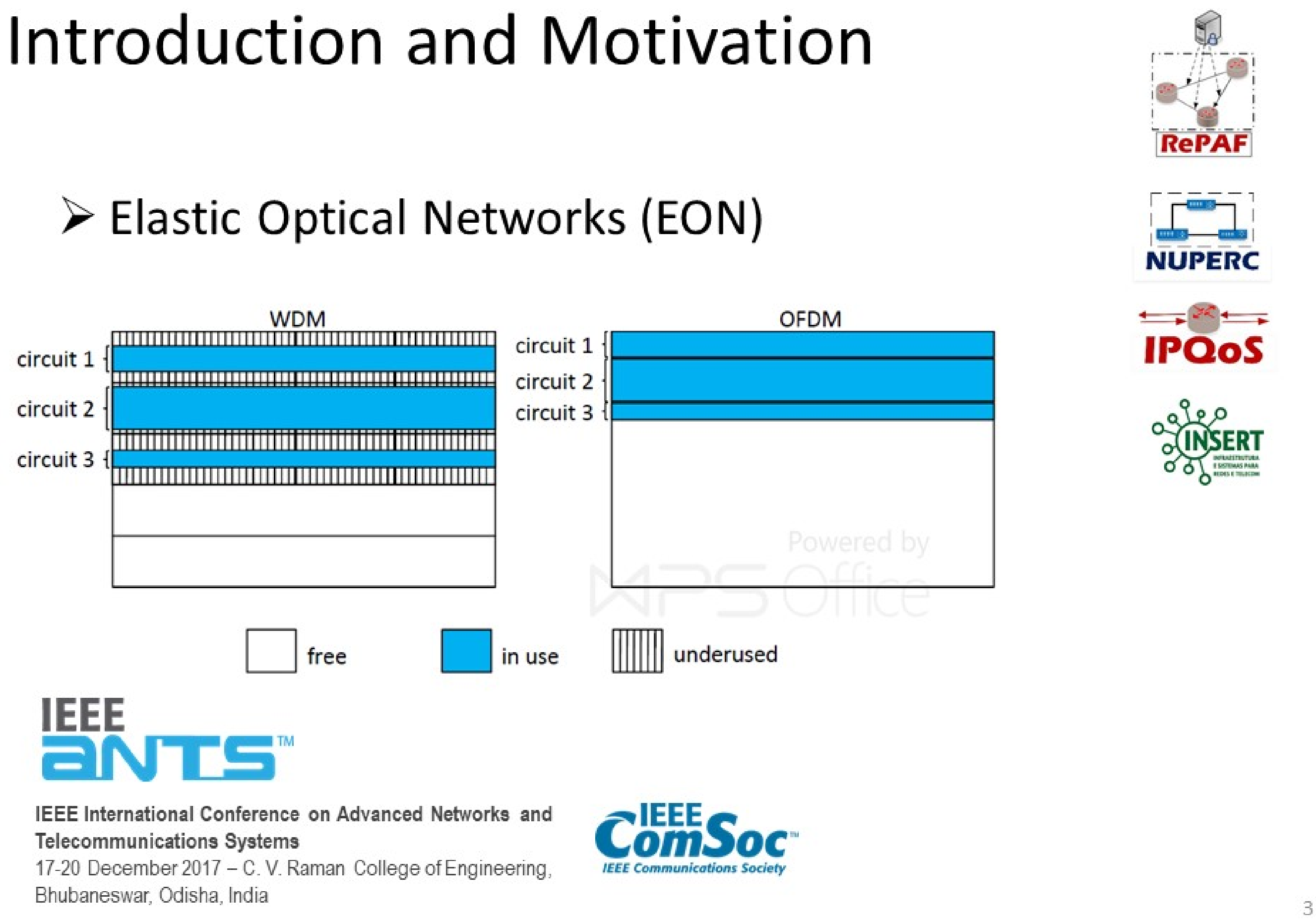

Fig. 3.

−− > **PAPER TEXT EXTRACT**:
"Nowadays, there is a growing interest in investigating the optical network architecture without the fixed wavelength grid (named gridless), in which network elements will support flexible bandwidth lightpaths. Thus, an optical path can occupy a free band of the spectrum exactly in accordance with the client's traffic demand. These networks were introduced in [6] and are known in the literature as Spectrum-Sliced Elastic Optical Path Network or Elastic Optical Networks [6] [7] (referred to as EON hereafter)."
"Bandwidth Allocation Models (BAMs) [8] [9] [10] can provide a new resource (slice) allocation strategy for EON. In effect, BAMs will provide EON network operations and management with a set of allocation strategies (BAM models and applications traffic class mappings and configuration) that may be dynamically adapted to current users demands in terms of application characteristics and traffic volume (the dynamic behavior of network clients and users)."

−− > Papers to read:

- The Maximum Allocation Model (MAM) is described in [8]
- The Russian Dolls Model (RDM) is described in [11] and [9]
- The AllocTC-Sharing (ATCS) model is described in [10]

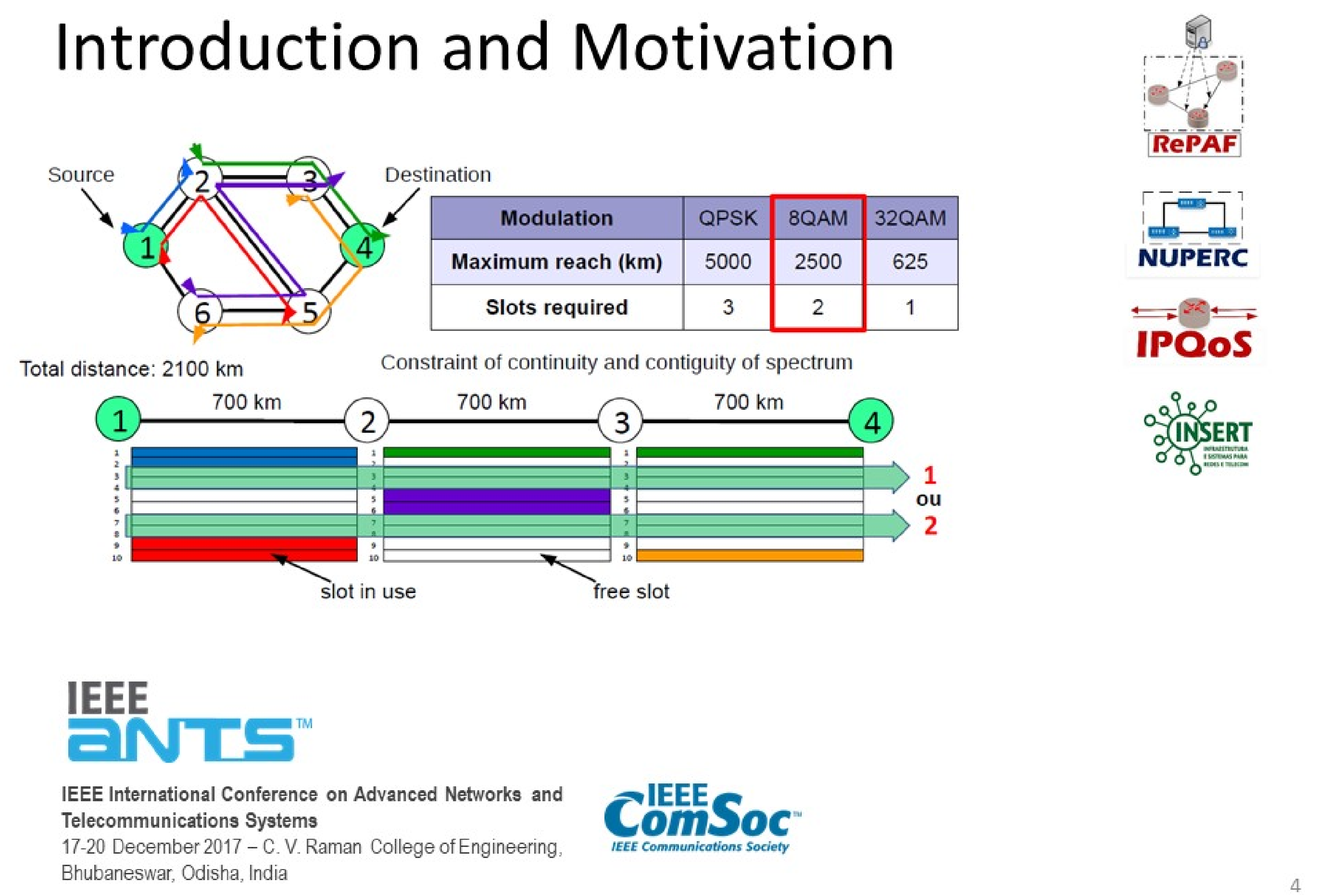

Fig. 4.

−− > **PAPER TEXT EXTRACT**:
"A first BAM contribution to allocate slots in EON is its ability to map services, users, applications requirements and priorities on a set of classes (TC – Traffic Classes). BAMs allow the configuration and management of application groups (TCs) that will have assigned resources and will be treated in an equivalent way in terms of resource allocation by the bandwidth allocation model used. The applications mapping considers a Service Level Agreement – SLA to comply with the QoS (Quality of Service) parameters that must be ensured by the service provider over the optical network."

−− > Paper to read - Related work (text from [1]):

- "In [12], Callegati et. al. propose and analyze a trunk reservation based strategy that aims to reduce the spectrum fragmentation. This approach focused on spectrum fragmentation and BAM-based resource allocation focus on network utilization among BAM models."
- "In [13], Hesselbach et. al. propose a specific resource allocation method for EON based on a modified RDM. The authors evaluate the mechanism proposed under different priority classes in a simple example. The result shows the better performance of the proposal when compared with MAM and RDM in terms of link utilization and acceptance ratio. This research adopts and compares only MAM and RDM modified models. Our proposal goes beyond and evaluates MAM, RDM and AllocTC-Sharing demonstrating that AllocTC-Sharing

behaves better than MAM and RDM approaches and, as such, presents an incremental contribution in terms of BAMs."

- "Authors in [14] use the RDM to allocate bandwidth for intra-Optical Network Unit in an Ethernet Passive Optical Network. The proposal achieves a superior performance when is compared with other two dynamic hierarchical bandwidth allocation algorithms in terms of bandwidth utilization, packet delay and fairness. This is another example where BAMs can be used to allocate resources. The comparison with the proposed EON approach is not direct but the reference illustrates another way BAMs can be adopted in the optical domain."

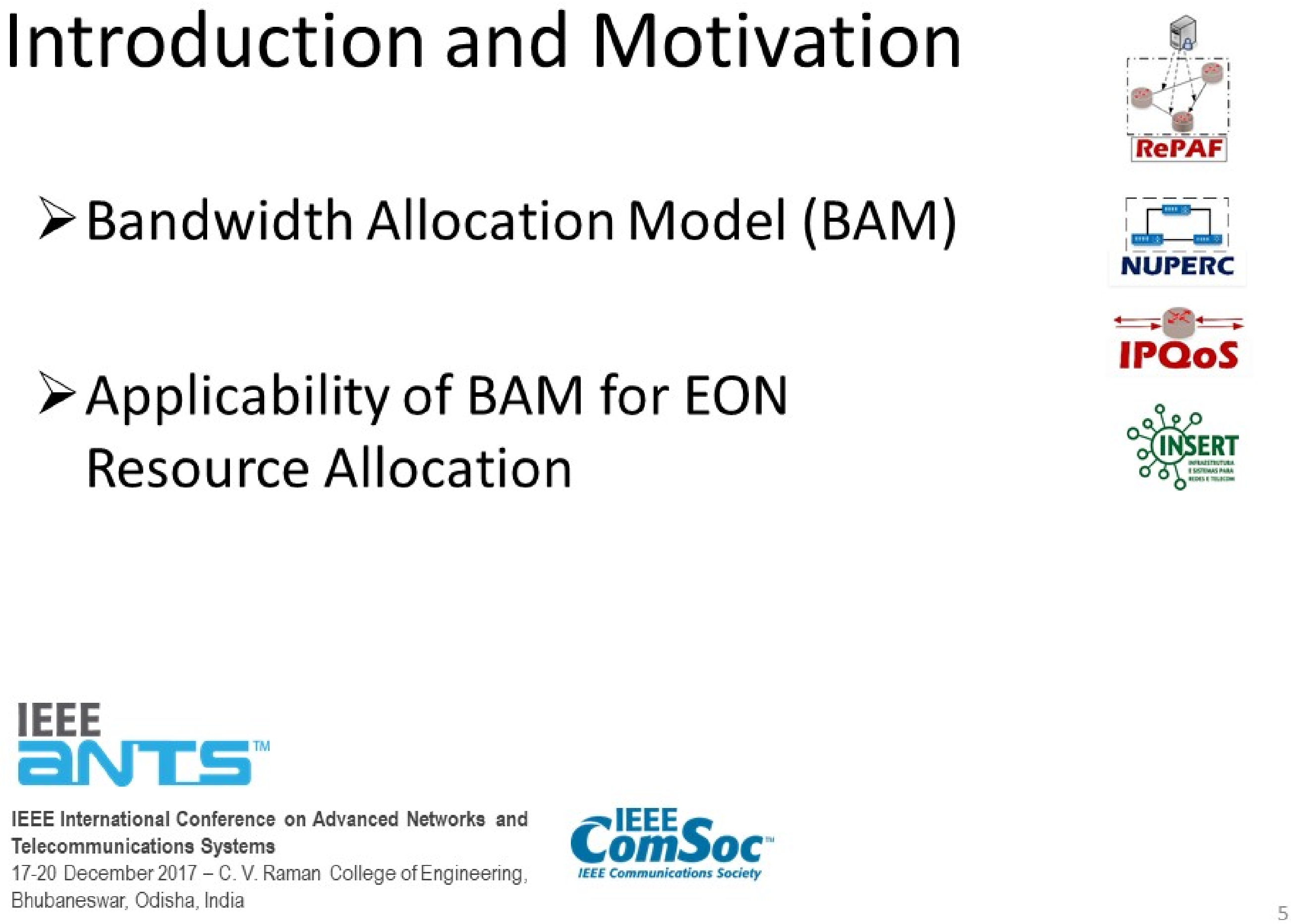

Fig. 5.

- **PAPER TEXT EXTRACT**:
  "BAM deployment will dynamically allow network management to adapt the resource allocation strategy in relation to the dynamicity of input traffic. In effect, each BAM model applied results in distinct network resource allocation strategies and distinct network performance. As an example, in case the network is submitted to a burst of high throughput consuming traffic like video streams, BAM utilization allows model switching in such a way that network utilization could be improved."
  "This paper proposes to evaluate the applicability of BAMs for EON resource allocation focusing on its ability to configure network users grouping and to adapt dynamically in relation to the type and volume of input traffic. In terms of this preliminary evaluation, it is expected that BAM's adoption will result in improving resources utilization for EON. The models proposed, as such, do not focus on service fairness and this aspect is not considered in this initial evaluation."

$-->$ Complementary paper to read:

  – The **RePAF Project** illustrates the general strategy in which slot allocation for EON with BAMs is one of various possible alternatives for BAM-based resource allocation [15].

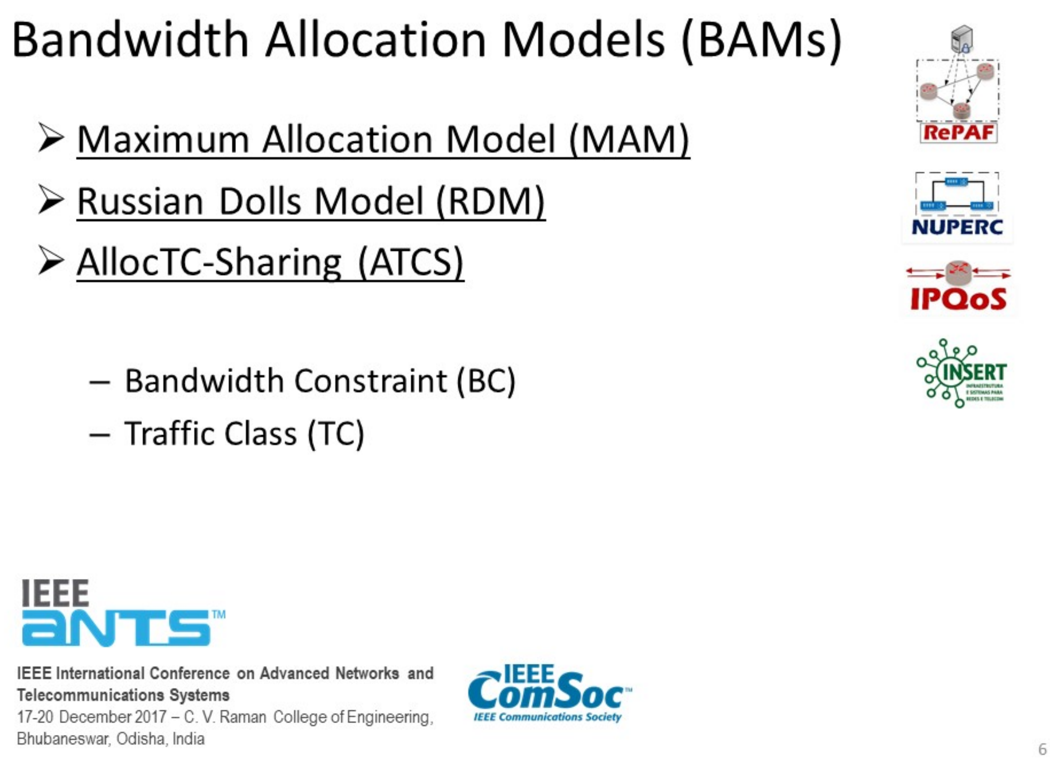

Fig. 6.

−− > **PAPER TEXT EXTRACT**:
"BAMs are used to define rules and limits for resource allocation by defining Bandwidth Constraints (BCs) or Resource Constraints (RCs) for traffic classes (TCs) [8] [11] [9] [10]. In practice, these models effectively define how resources are obtained and shared among applications and/or clients."

GitHub

Fig. 7.

−− > Complementary information (download):

– For those interested in exploring BAM operations, BAMSDN tool [1] allows LSP (Label Switched Path) creation in a MPLS network using OpneFlow/ SDN in the control plane.
– **The BAMSDN Tool is available for download at GITHUB: https://github.com/EliseuTorres/BAMSDN**

1. Available for download at https://github.com/EliseuTorres/BAMSDN

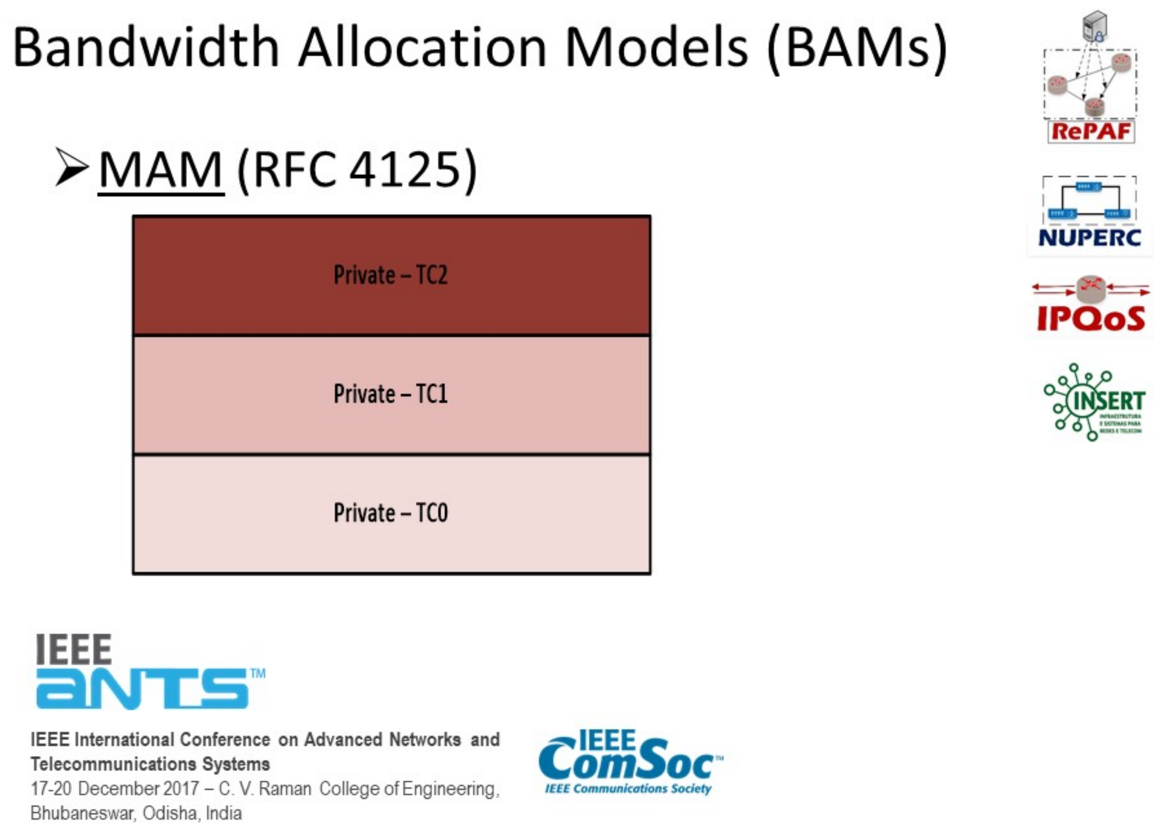

Fig. 8.

$-->$ **PAPER TEXT EXTRACT**:
"The MAM model targets network traffic patterns in which a strong isolation between traffic classes (TCs) is required [8]. This characteristic is valid for both optical and IP traffic demands. In this model, TCs use only private resources and there is no resource sharing among TCs."

$-->$ Papers to read:

- A general description of BAM operations is presented in [4].
- A discussion about BAM configuration management and BAM model switching is presented in [16] and [3].

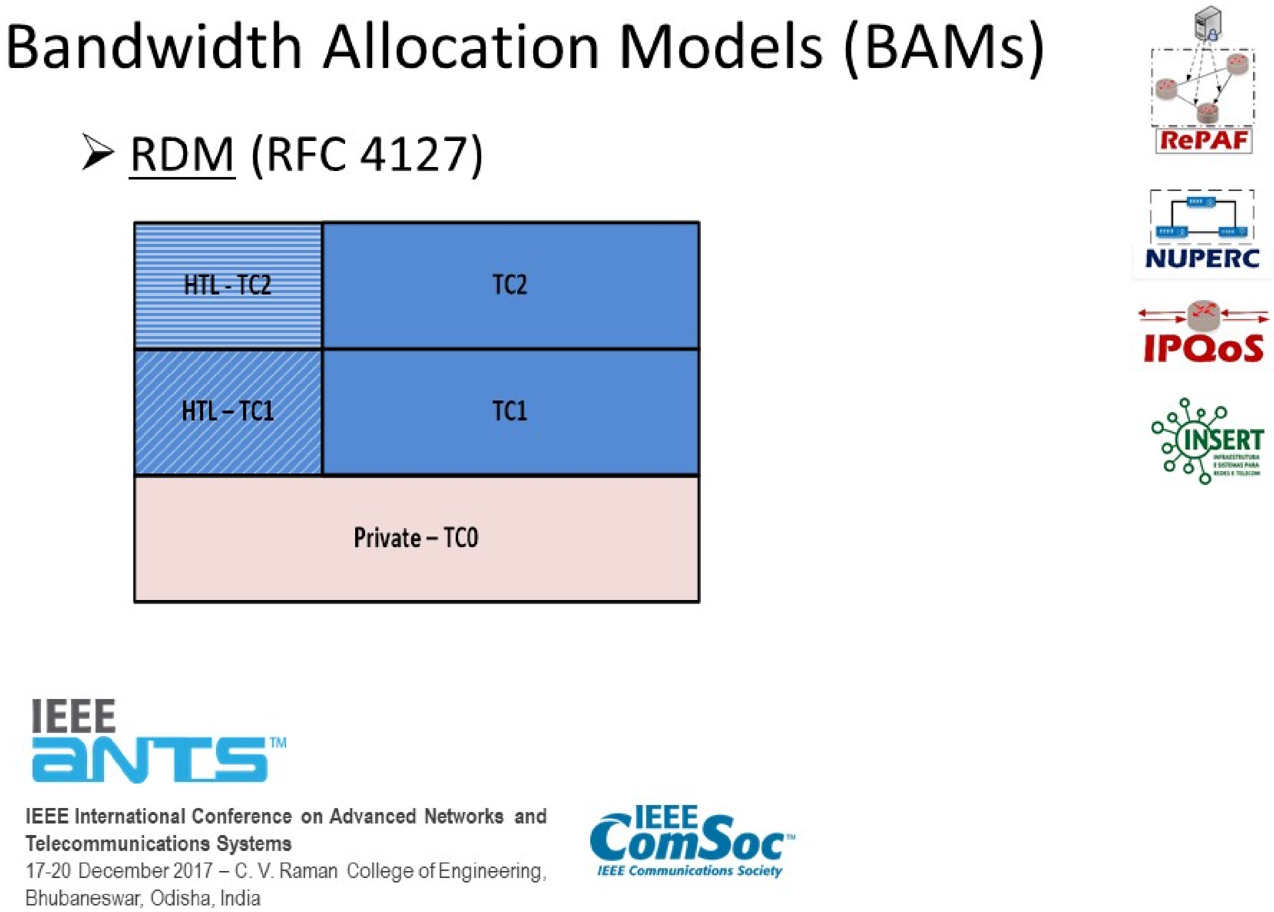

Fig. 9.

$-- >$ **PAPER TEXT EXTRACT**:
"RDM model allows the sharing of non-allocated resources belonging to high priority traffic classes by low priority traffic classes (HTL sharing) [11]. This model tends to improve resource utilization for a network traffic profile in which a large volume of low priority TCs and/or applications is demanding network resources."

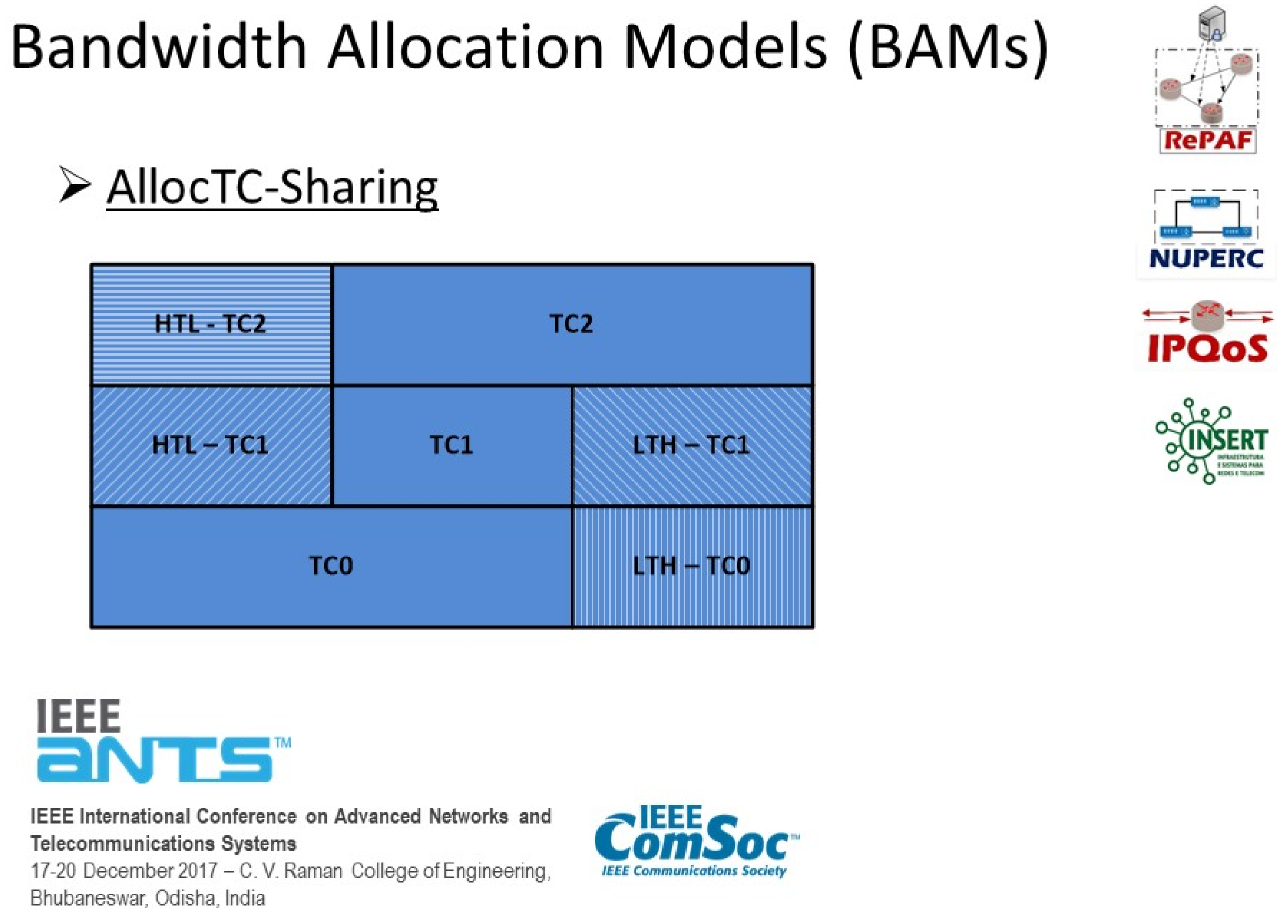

Fig. 10.

$--\!>$ **PAPER TEXT EXTRACT**:
"AllocTC-Sharing (ATCS) model keeps RDM resource allocation strategy of "High-To-Low" loans and adds the possibility of "Low-To-High" loans (LTH sharing). As such, AllocTC-Sharing allows high priority classes (TCs) to get resources normally used by low priority classes (TCs). In brief, "loans" are allowed in both directions (HTL e LTH). This model targets networks in which the input traffic has a highly dynamic profile with weak isolation among TCs being acceptable. This corresponds, as an example, to networks with high priority elastic applications like multimedia services, among others [17]."

$--\!>$ Paper to read:

- The AllocTC-Sharing (ATCS) model **was proposed by Reale et al. and is presented in [10]**.

Bandwidth Allocation Models (BAMs)

BAM – General Behavioral Characteristics	MAM	RDM	ATCS
Resource utilization with a traffic profile composed by a large amount of low priority traffic.	*Low*	*High*	*High*
Resource utilization with a traffic profile composed by a large amount of high priority traffic	*Low*	*Low*	*High*
TCs isolation.	*High*	*Medium*	*Low*
BAM Operational Characteristics	**MAM**	**RDM**	**ATCS**
"High-to-Low" (HTL) sharing.	*No*	*Yes*	*Yes*
"Low-to-High" (LTH) sharing.	*No*	*No*	*Yes*

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Fig. 11.

$-->$ **PAPER TEXT EXTRACT**:
"The main proposed BAMs for IP/MPLS/DS-TE networks like MAM – Maximum Allocation Model, RDM – Russian Dolls Model and ATCS – AllocTC-Sharing have distinct operations characteristics, from now on called "behaviors". Each BAM treat the input traffic profile with a different "behavior" and, as such, optimization may differ among distinct BAM models. Figure 11 resumes the expected BAMs resource (link, lambda, slot) allocation "behavior" characteristics for distinct network traffic profiles. It is observed that utilization might be compromised depending on the input traffic pattern and currently adopted BAM [3]."

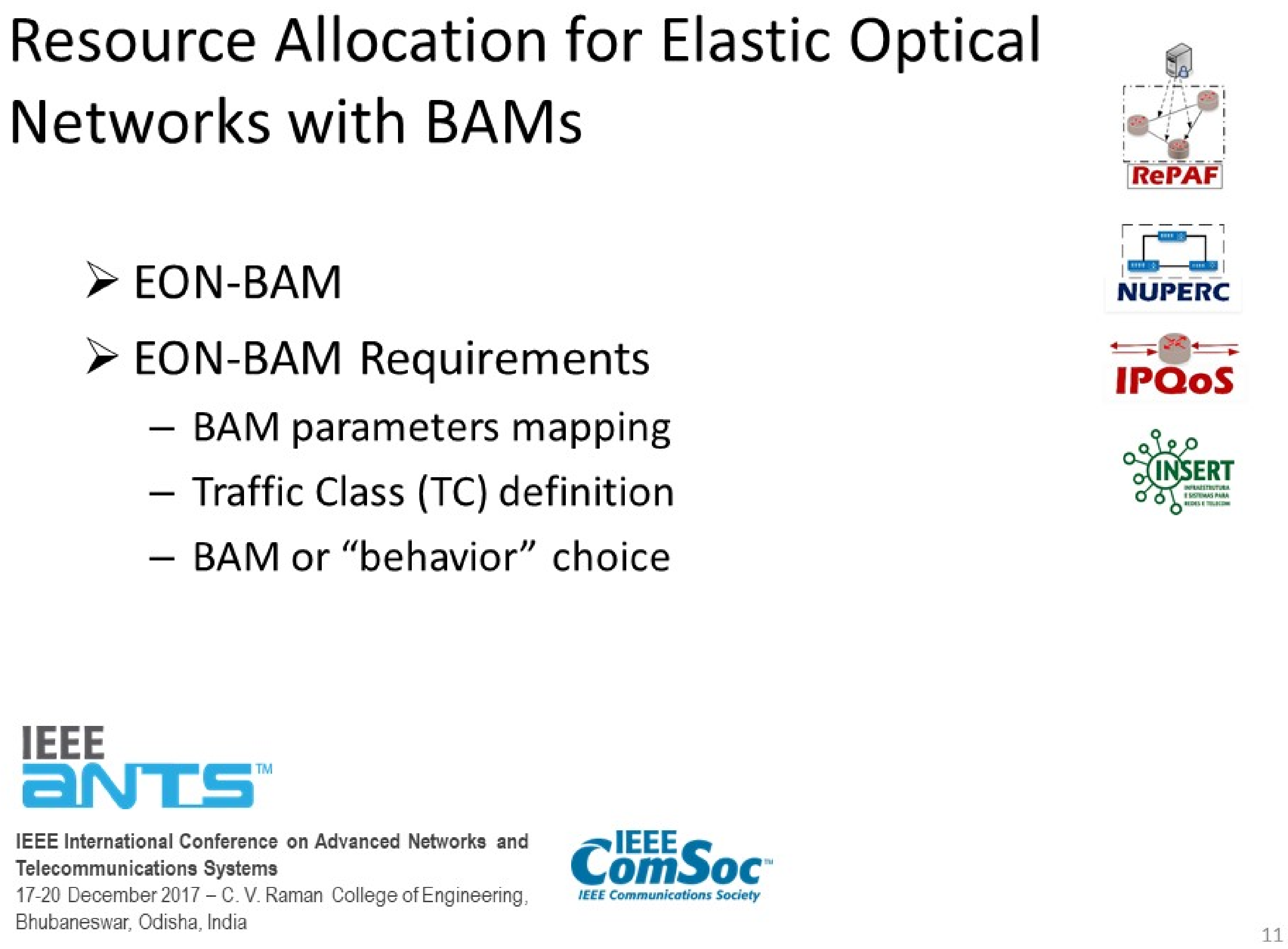


Fig. 12.

−− > **PAPER TEXT EXTRACT**:
"EON-BAM approach requires a "BAM parameters mapping", Traffic Class (TC) definition and BAM model or "behavior" choices by the network operation and management for the specific EON scenario."

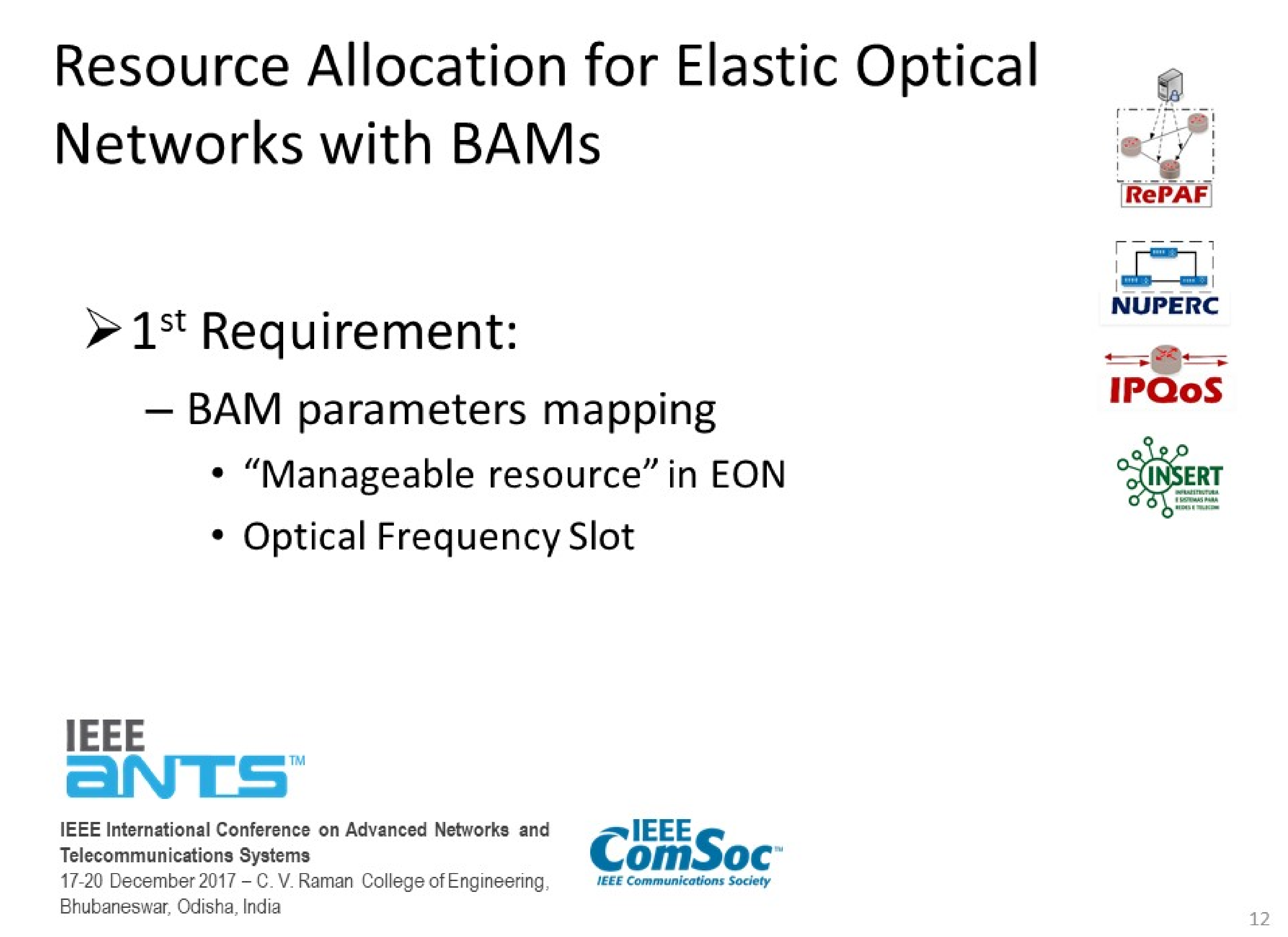


Fig. 13.

−− > **PAPER TEXT EXTRACT**:
"In terms of the BAM parameters mapping and for simplicity, the "manageable resource" defined for allocation and/or sharing in EON is the optical frequency slot [6] [7] [18] [19]. It is noteworthy that, depending on the level of abstraction (scenario modeling defined), nothing prevents to consider other optical manageable resources in the BAM to EON-BAM mapping, such as optical converters and transceivers."

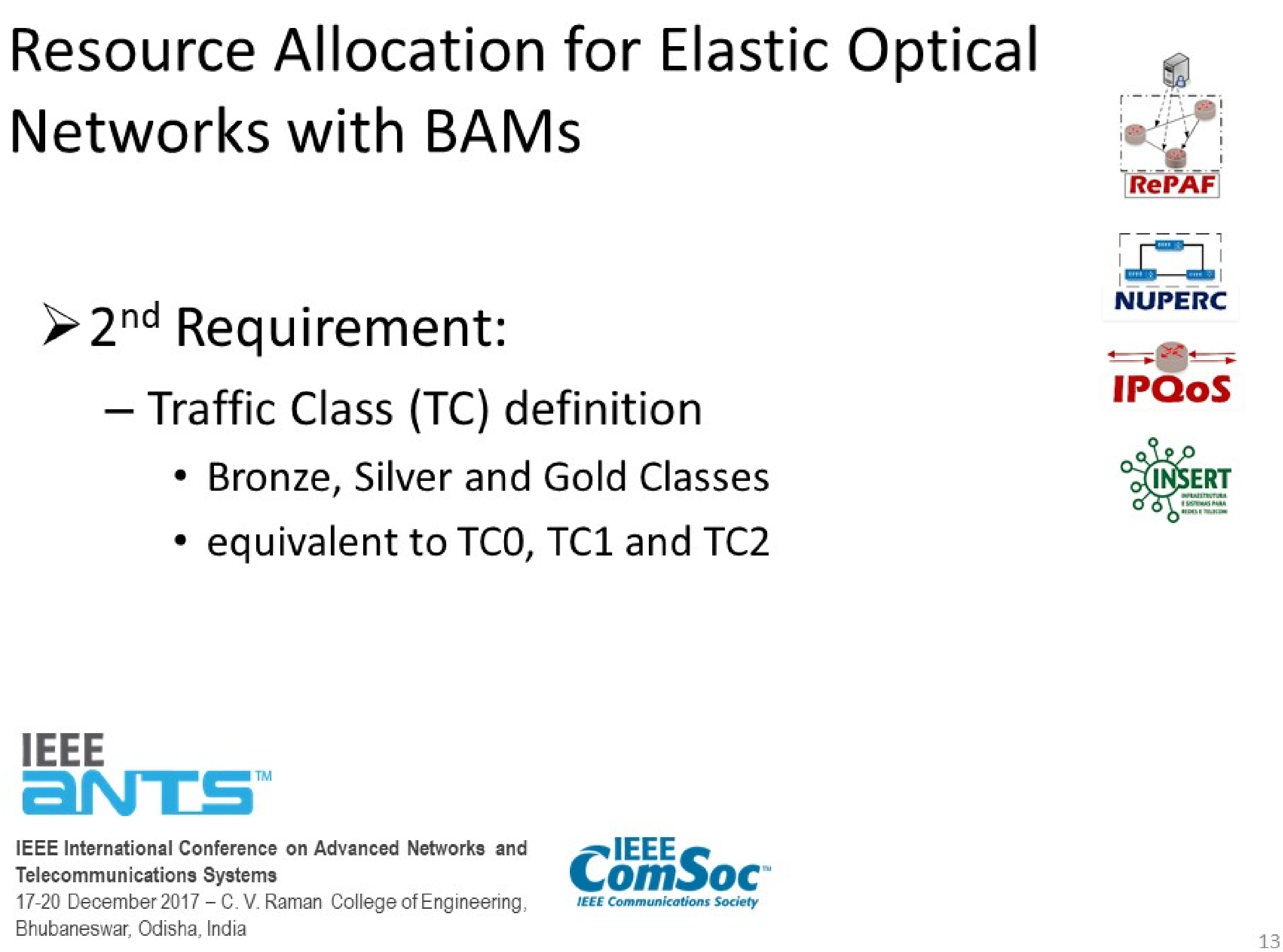


Fig. 14.

−− > **PAPER TEXT EXTRACT**:

"Traffic Classes (TCs) are defined and configured by the network operation and management instance and, considering the target of this paper, 03 TCs are defined as follows:

- Bronze, Silver and Gold Classes (equivalent to TC0, TC1 and TC2 in the simulation scenario following).
- TC0 (bronze) class aggregates applications, as an example of preliminary mapping, with low priority and possibly no or less demanding constraints.
- TC1 (silver) class aggregates applications with intermediate priorities and more restricted constraints in relation to TC0.
- TC2 (gold) class aggregates applications with higher priority and more restricted constraints."

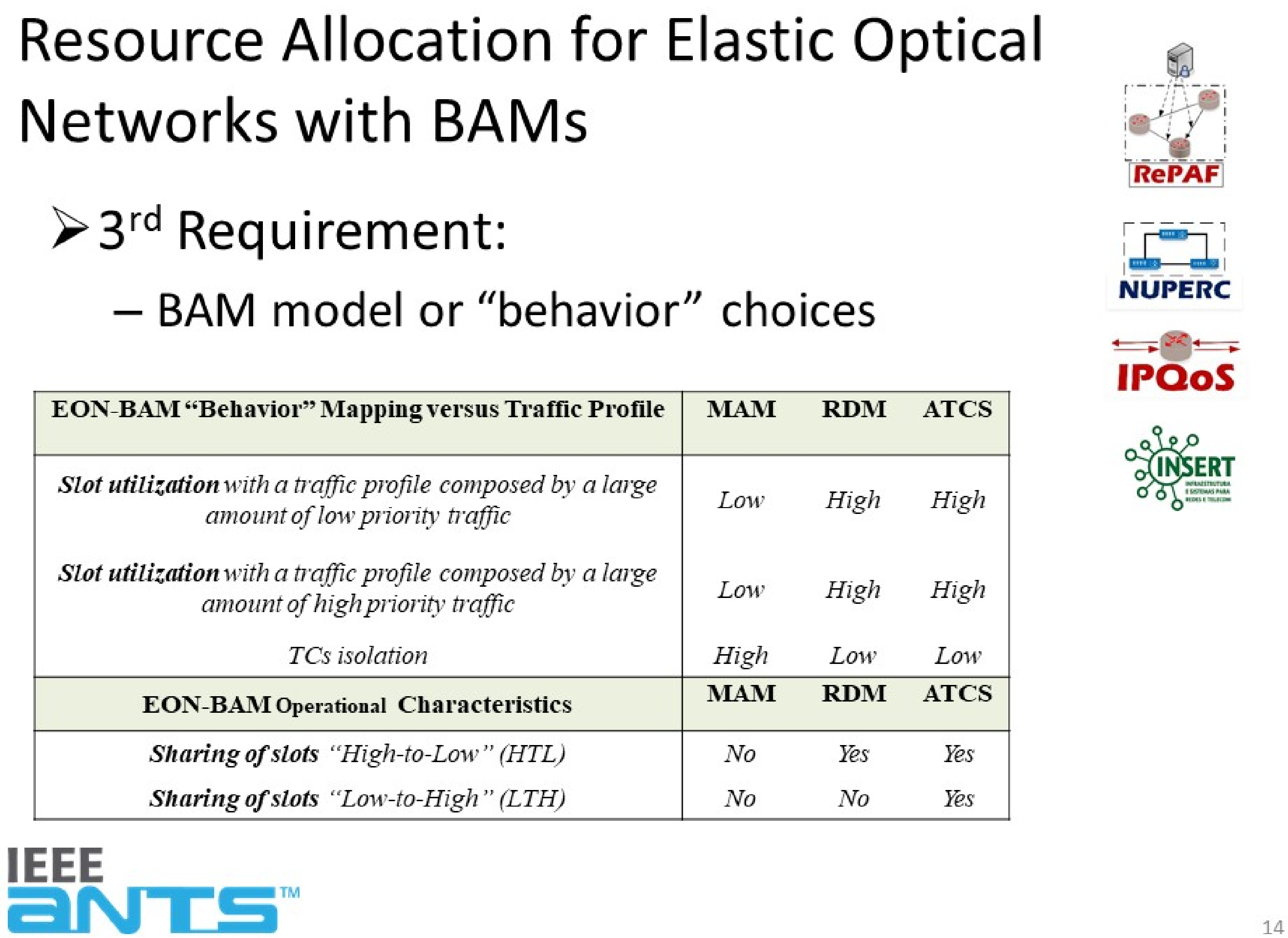


Fig. 15.

−− > **PAPER TEXT EXTRACT**:
"The BAM model to be used ("behavior") is the third aspect to consider in the EON-BAM approach. Figure 15 shows a set of possible EON-BAM behaviors mappings in relation to traffic profile. In other words, Figure 15 indicates what EON-BAM slot utilization can be expected depending on which BAM was defined (configured) for slot allocation for distinct traffic profiles. It is relevant to observe that the expected traffic profile plays an important role since BAMs behaviors are directly dependent of traffic. That also means EON-BAM must be evaluated (simulated) against the various BAM alternatives."

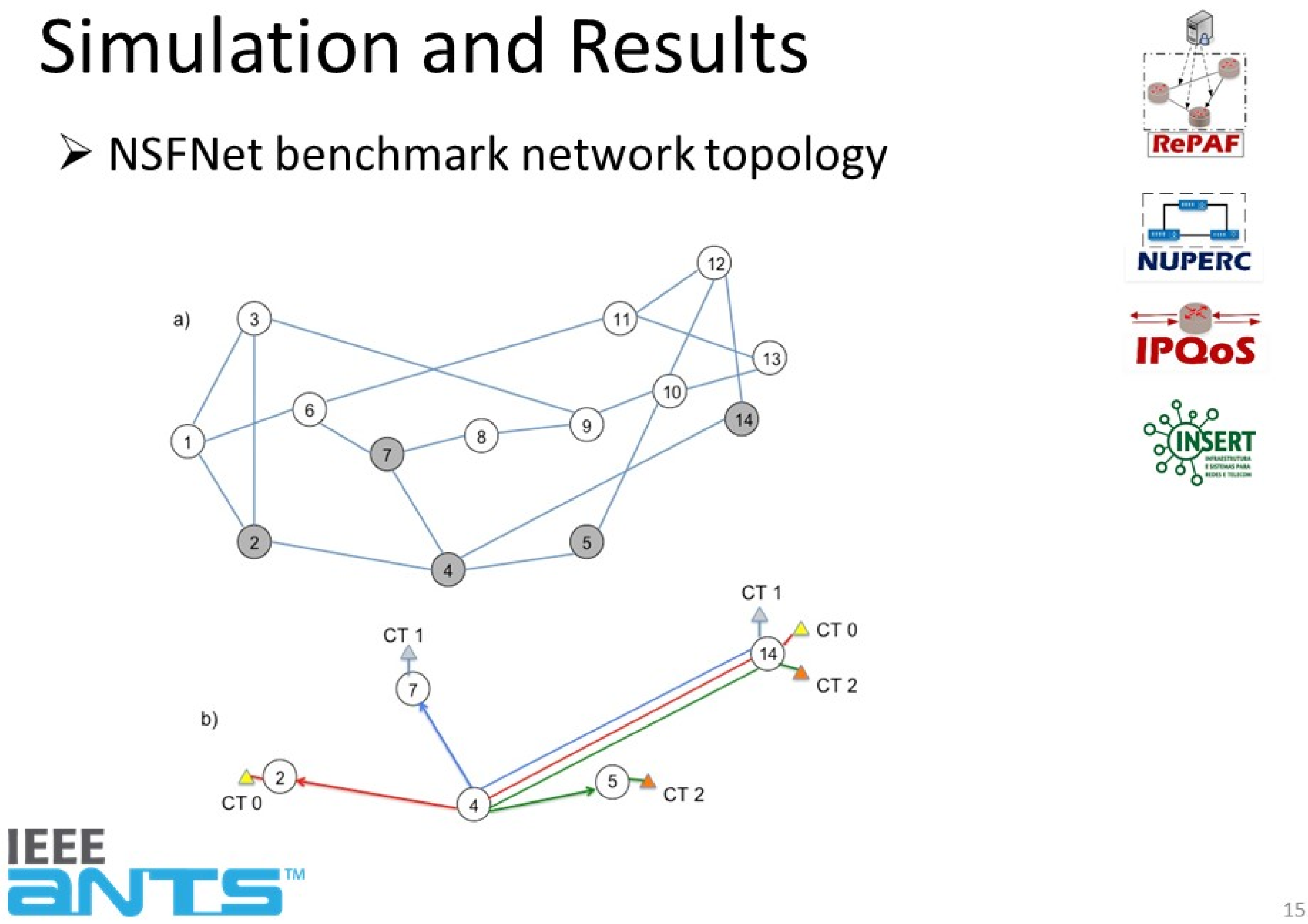


Fig. 16.

−− > **PAPER TEXT EXTRACT**:
"Figure 16a illustrates the NSFNet network topology. Figure 16b shows the nodes of the NSFNet topology used in our simulations considering node 14 as the source node of all optical connections requests (lightpaths) and nodes 2, 7 and 5 as destination nodes of lightpaths for Bronze, Silver and Gold traffic classes. The simulation topology (Figure 1b) and the traffic pattern modeled is intended to simplify the routing and the impact of continuity aware spectrum allocation that is out of scope in this preliminary evaluation work. It is important to remark that previous simulated BAM switching approaches (discussed in [3]) with IP networks effectively show their utilization characteristics with partial topologies. Since the objective is to evaluate the utilization improvement with distinct BAMs, it basically requires a scenario where the traffic pattern experiences moments of congestion for all classes."

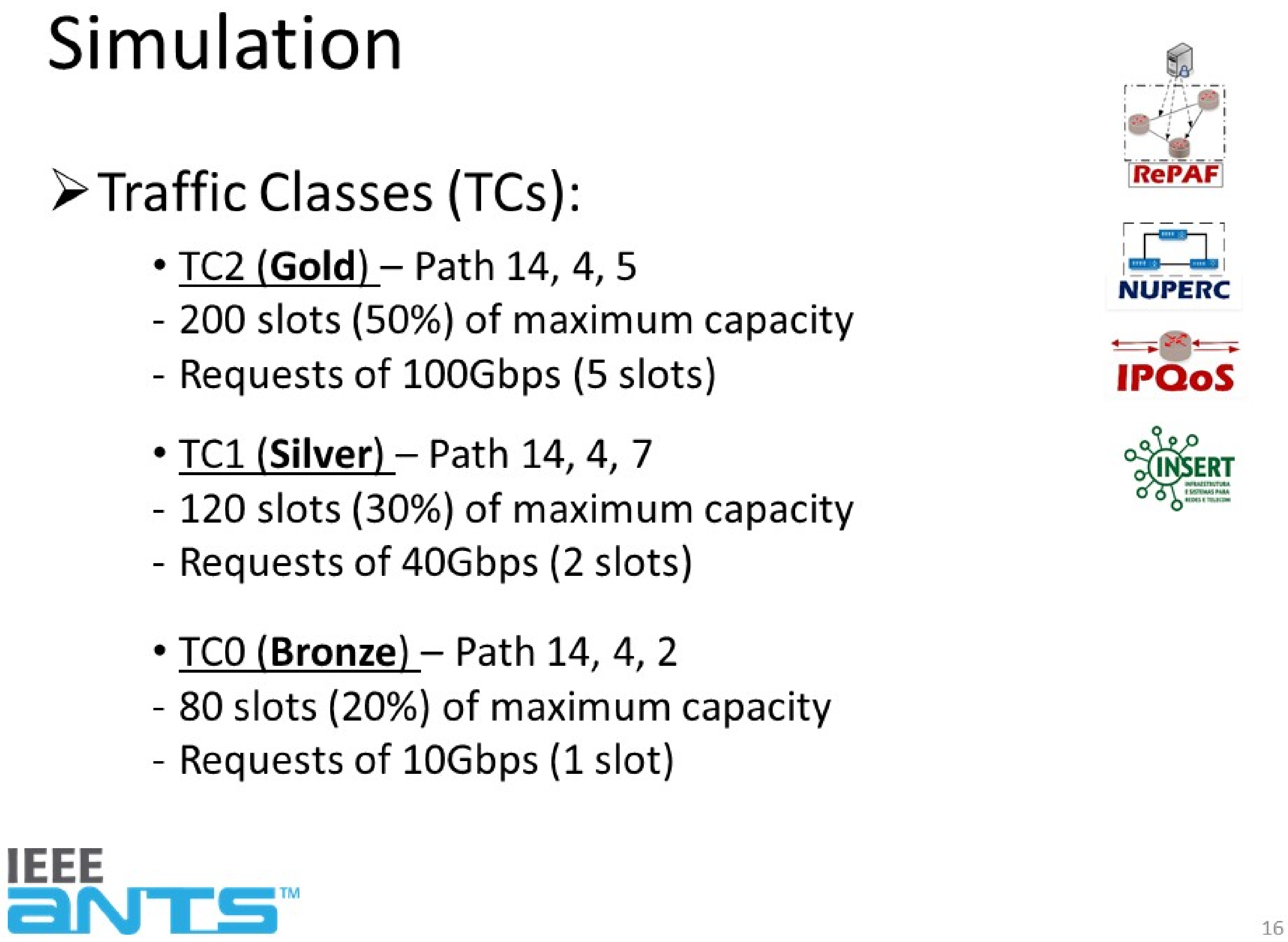


Fig. 17.

−− > **PAPER TEXT EXTRACT**:

"The configuration parameters of the simulation scenarios are as follows:

- Link: 400 slots (OFDM);
- Traffic Classes: TC0 (Bronze), TC1 (Silver) and TC2 (Gold);
- Resource Constraints, according to Tables in Figure 19."

"The Traffic Classes have the following characteristics:

- TC0 (Bronze) – Path 14, 4, 2; 80 slots of maximum capacity (20% of network resources); requests of 10Gbps using BPSK modulation, which is equivalent to one slot.
- TC1 (Silver) – Path 14, 4, 7; 120 slots of maximum capacity (30% of network resources); requests of 40Gbps using BPSK modulation, which is equivalent to 2 slots.
- TC2 (Gold) – Path 14, 4, 5; 200 slots of maximum capacity (50% of network resources); requests of 100Gbps using BPSK modulation, which is equivalent to 5 slots."

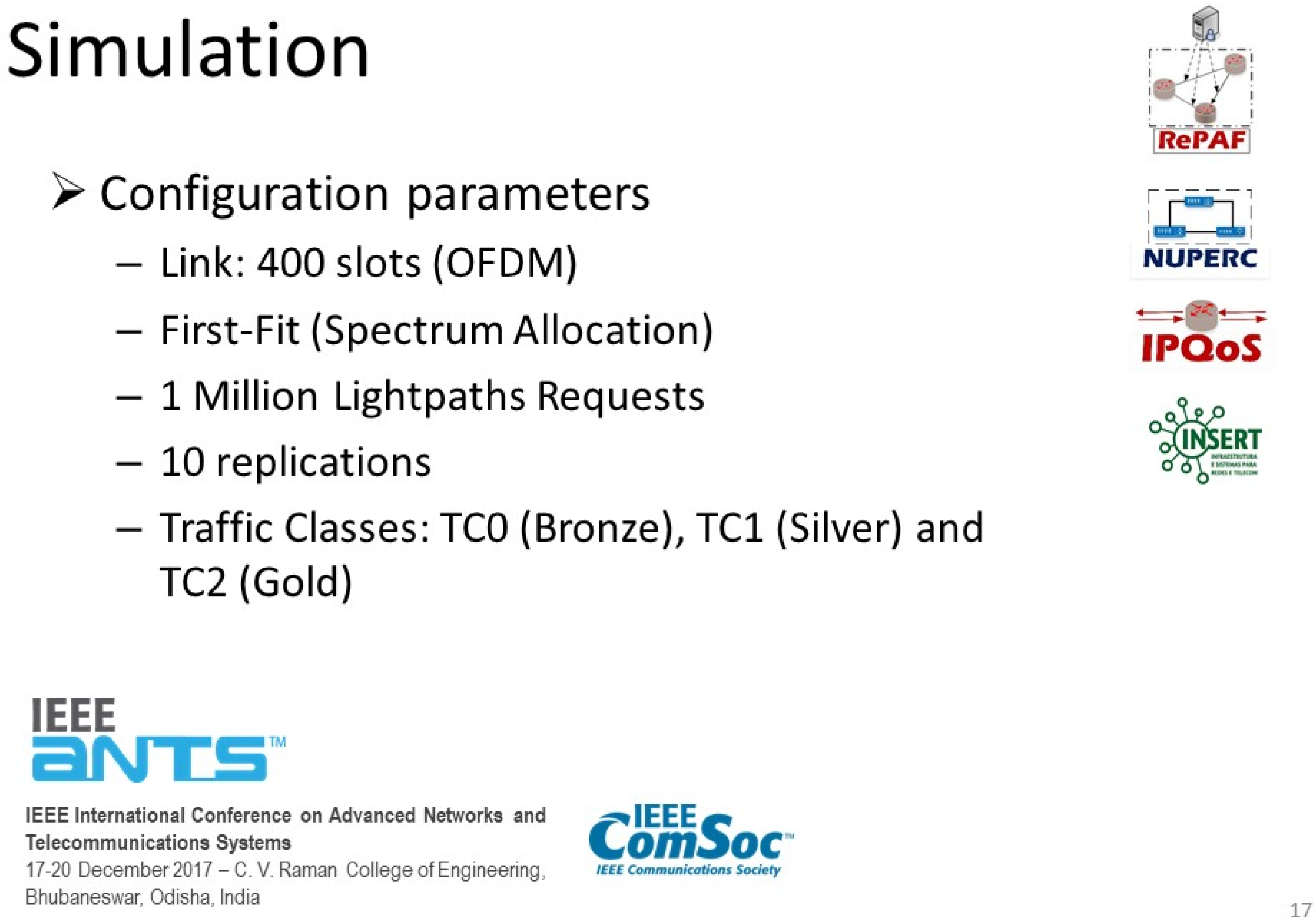
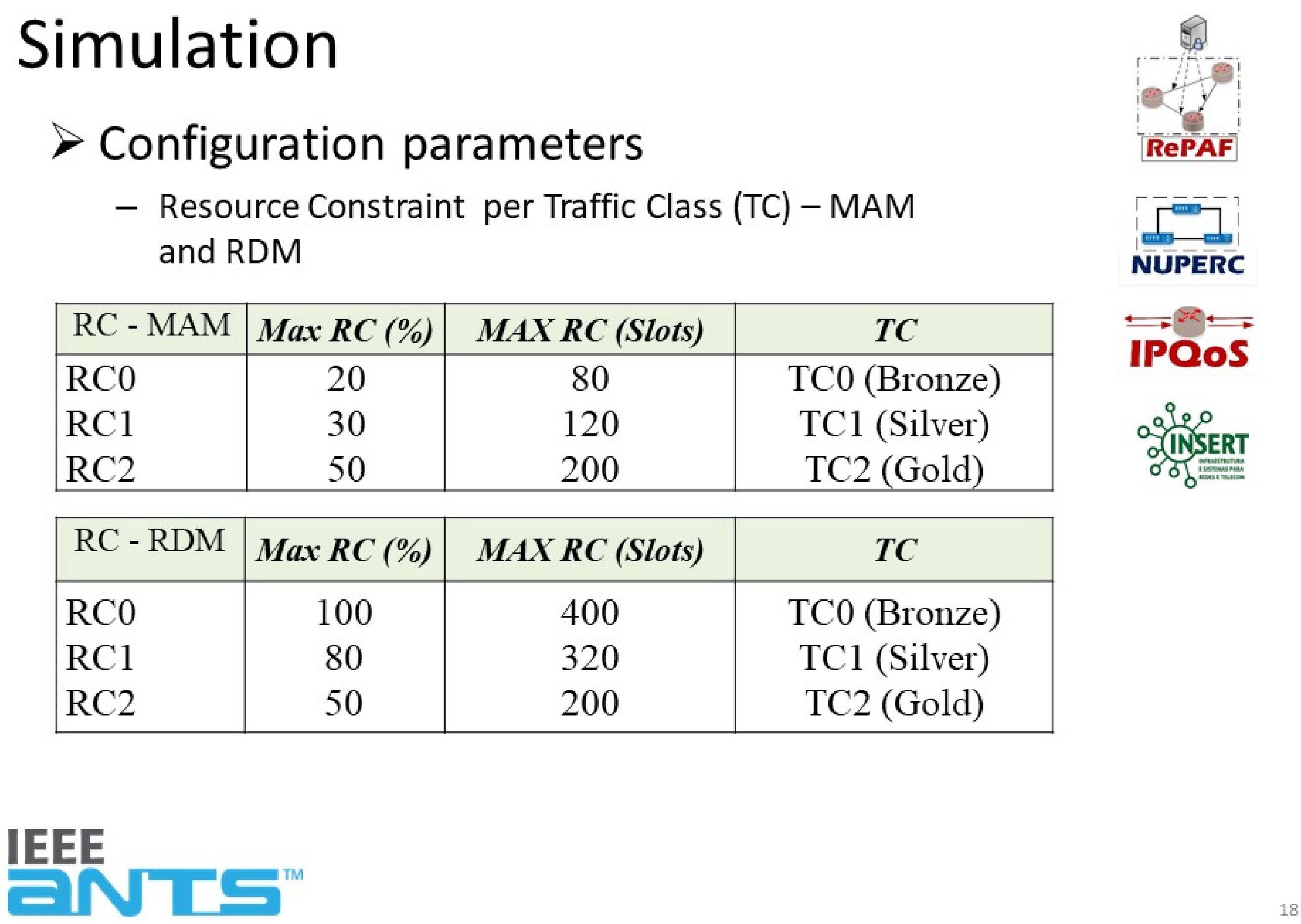


Fig. 18.

−− > **PAPER TEXT EXTRACT**:
"In all evaluated scenarios, the hold time of lightpaths is modeled exponentially with a mean of 2500h. The spectrum allocation algorithm used was First-Fit [14]. There were generated one million lightpaths requests with 10 replications."



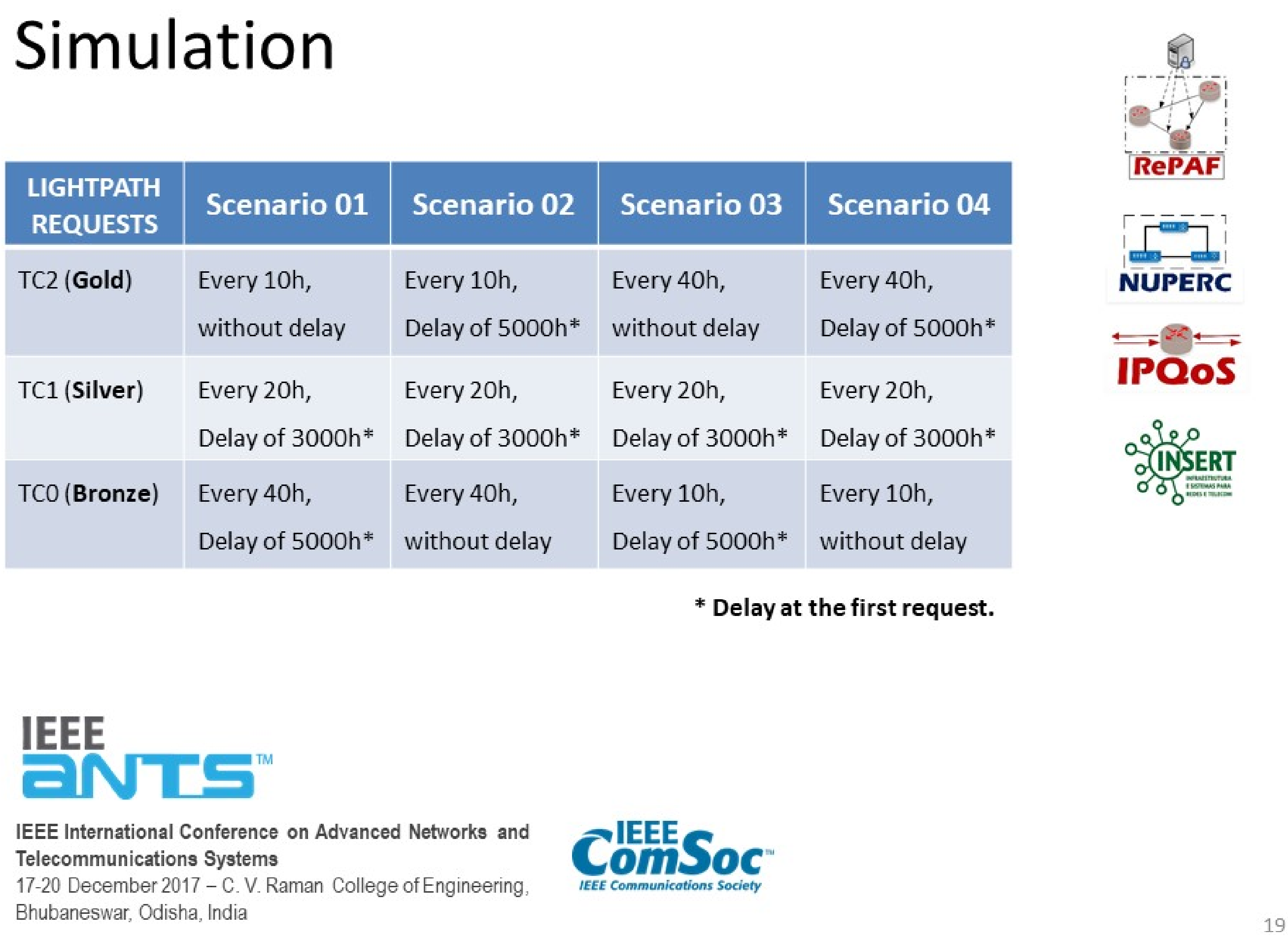
RC - MAM	*Max RC (%)*	*MAX RC (Slots)*	*TC*
RC0	20	80	TC0 (Bronze)
RC1	30	120	TC1 (Silver)
RC2	50	200	TC2 (Gold)

RC - RDM	*Max RC (%)*	*MAX RC (Slots)*	*TC*
RC0	100	400	TC0 (Bronze)
RC1	80	320	TC1 (Silver)
RC2	50	200	TC2 (Gold)

Fig. 19.

−− > **PAPER TEXT EXTRACT**:
"The configuration parameters of the simulation scenarios are as follows:

– Link: 400 slots (OFDM);
– Traffic Classes: TC0 (Bronze), TC1 (Silver) and TC2 (Gold);
– Resource Constraints, according to Tables in Figure 19."



Simulation

LIGHTPATH REQUESTS	Scenario 01	Scenario 02	Scenario 03	Scenario 04
TC2 (**Gold**)	Every 10h, without delay	Every 10h, Delay of 5000h*	Every 40h, without delay	Every 40h, Delay of 5000h*
TC1 (**Silver**)	Every 20h, Delay of 3000h*	Every 20h, Delay of 3000h*	Every 20h, Delay of 3000h*	Every 20h, Delay of 3000h*
TC0 (**Bronze**)	Every 40h, Delay of 5000h*	Every 40h, without delay	Every 10h, Delay of 5000h*	Every 10h, without delay

*** Delay at the first request.**

Fig. 20.

−− > **PAPER TEXT EXTRACT**:
"The scenarios evaluated are as follows:

- Scenario 01: arrival rate for TCs of higher priority is higher than arrival rate for TCs of lower priority. Traffic generated is initially higher for TCs of lower priority and then gets higher for all classes.
- Scenario 02: arrival rate for TCs of higher priority is higher than arrival rate for TCs of lower priority. Traffic generated is initially higher for TCs of higher priority and then gets higher for all classes.
- Scenario 03: arrival rate for TCs of lower priority is higher than arrival rate for TCs of higher priority. Traffic generated is initially higher for TCs of lower priority and then gets higher for all classes.
- Scenario 04: arrival rate for TCs of lower priority is higher than arrival rate for TCs of higher priority. Traffic generated is initially higher for TCs of higher priority and then gets higher for all classes."

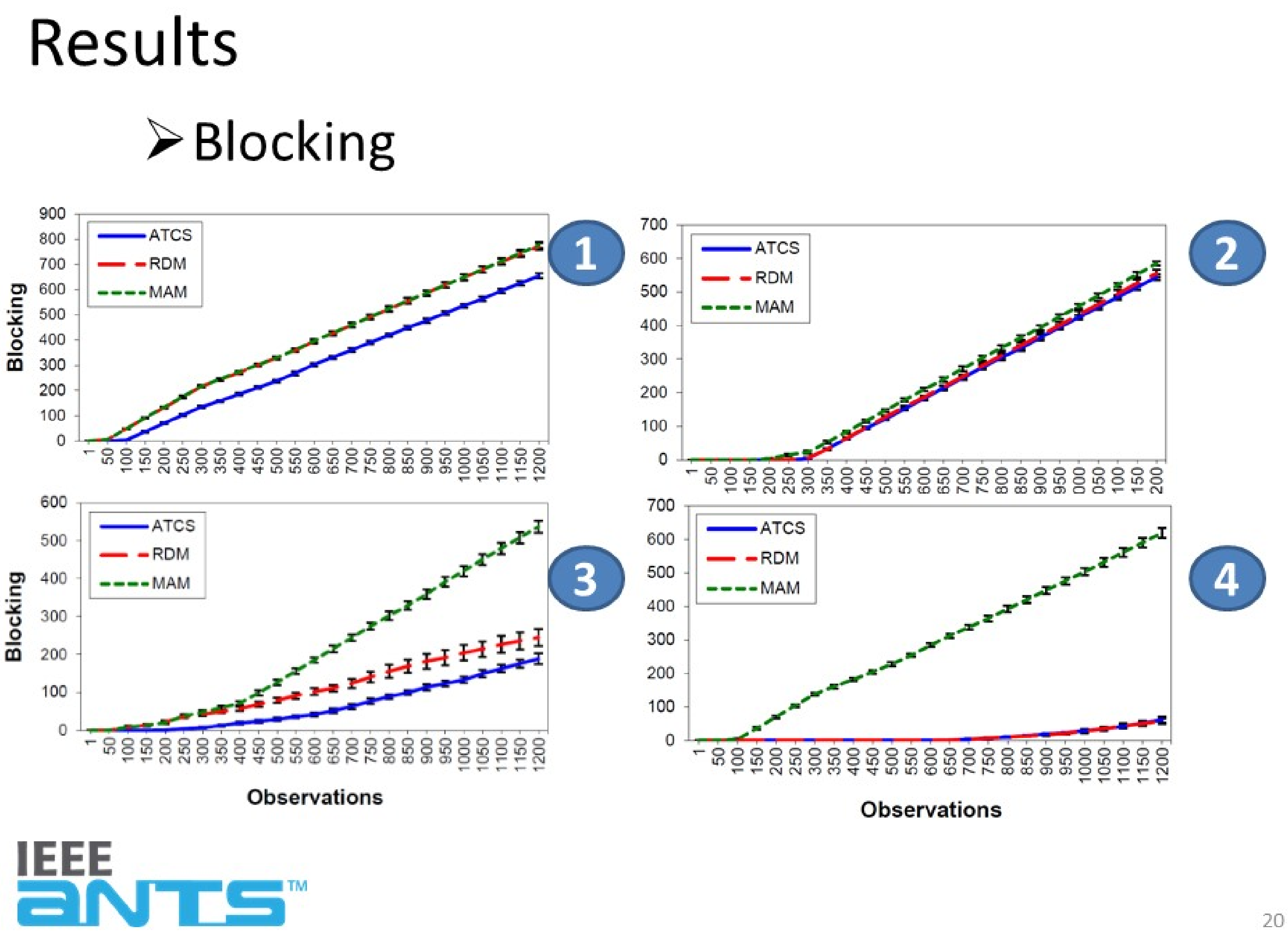


Fig. 21.

−− > **PAPER TEXT EXTRACT**:

"In all scenarios, the following performance metrics were evaluated:

- Blocking – computed unestablished lightpaths;
- Slots utilization – the effective slot utilization; and
- Established lightpaths – number of established lightpaths."

"It can be noticed in Figure 21.1 (scenario 1) that the ATCS BAM model has lower number of blocked lightpaths when compared to other BAM models. This behavior is explained by the fact that in this scenario are generated more requests of high priority classes. The ATCS model allows better resource sharing among classes through loans, such as "low-to-high", that does not occur with other BAM models."

"It is noted in Figure 21.2 that the BAM models have similar values for blocked lightpaths. Such behavior is justified mainly by the fact that in the scenario 2, despite the higher rate of arrival of higher priority classes, these classes have a delay at the beginning of the simulated traffic."

"It is noted in Figure 21.3 that the ATCS model presents lower lightpaths blocking when compared with other bandwidth allocation models. Such behavior is justified by the fact that in this scenario are first generated requests for higher priority classes and in this scenario, the ATCS model allows better sharing of resources among the classes, through "low to high" loans, which does not occur with other evaluated models."

"It is noted in Figure 21.4 that the MAM model showed higher lightpath blocking when compared with other BAMs. Such behavior is justified because in this scenario are generated more lower priority classes requests. In this scenario, the MAM model does not allow the sharing of resources among classes, which does not occur with other configured models. Both RDM and ATCS allow the "top down" sharing resulting in lower request blocking."

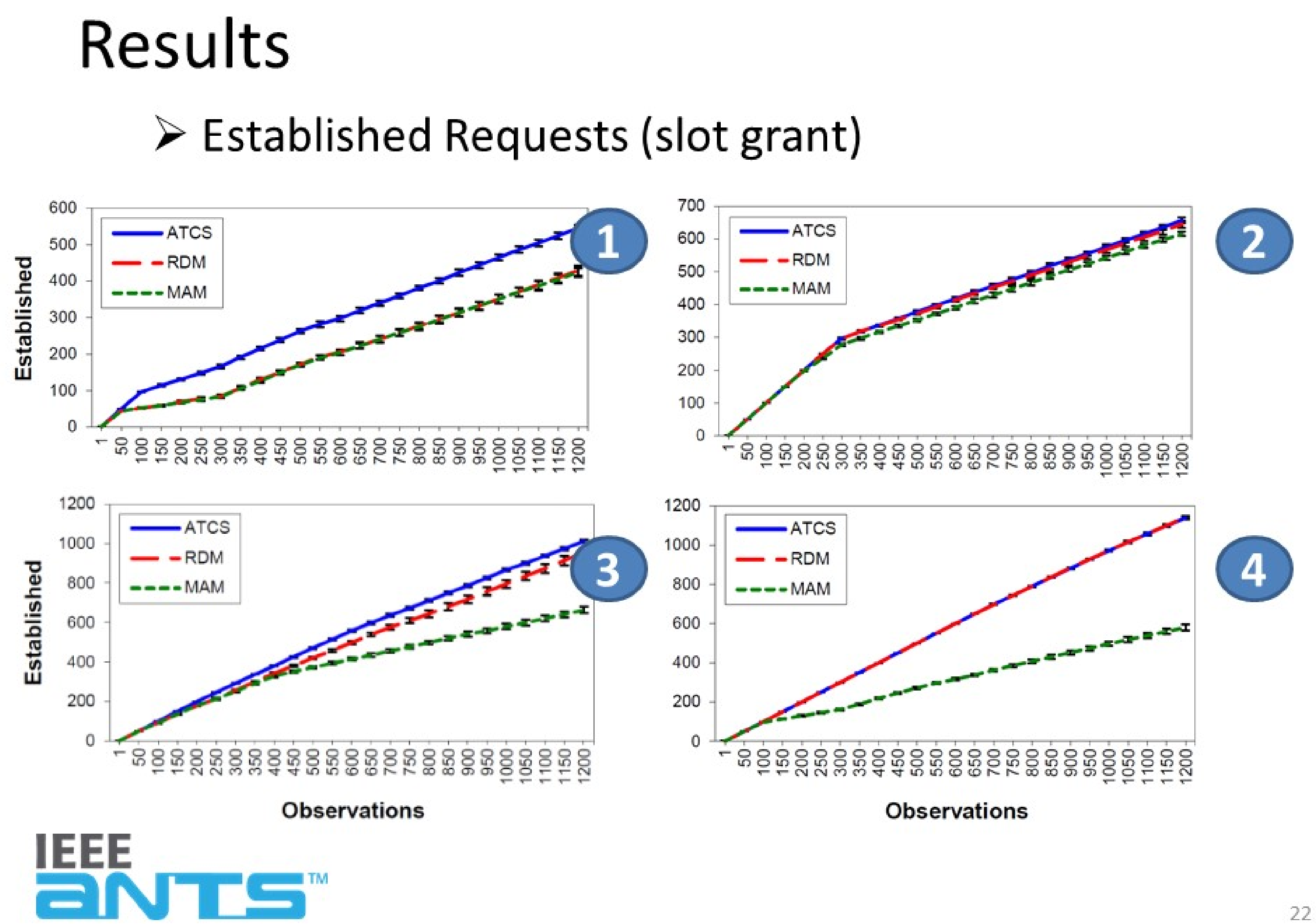


Fig. 22.

−− > **PAPER TEXT EXTRACT**:
"In all scenarios, the following performance metrics were evaluated:

– Blocking – computed unestablished lightpaths;
– Slots utilization – the effective slot utilization; and
– Established lightpaths – number of established lightpaths."

"It can be noticed in Figure 21.1 (scenario 1) that the ATCS BAM model has lower number of blocked lightpaths when compared to other BAM models. Consequently, as illustrated in Figure 22.1, the ATCS model succeeds to establishes a greater number of lightpath requests."

"It is noted in Figure 21.2 that the BAM models have similar values for blocked lightpaths. Consequently, as illustrated in 22.2, the resource allocation models attend a similar number of lightpaths requests."

"It is noted in Figure 21.3 that the ATCS model presents lower lightpaths blocking when compared with other bandwidth allocation models. Consequently, as illustrated in Figure 22.3, with the ATCS model it can be established a greater number of lightpaths requests."

"It is noted in Figure 21.4 that the MAM model showed higher lightpath blocking when compared with other BAMs. Consequently, as illustrated in Figure 22.4, the MAM model establishes a smaller number of lightpath requests when compared with other evaluated BAM models."

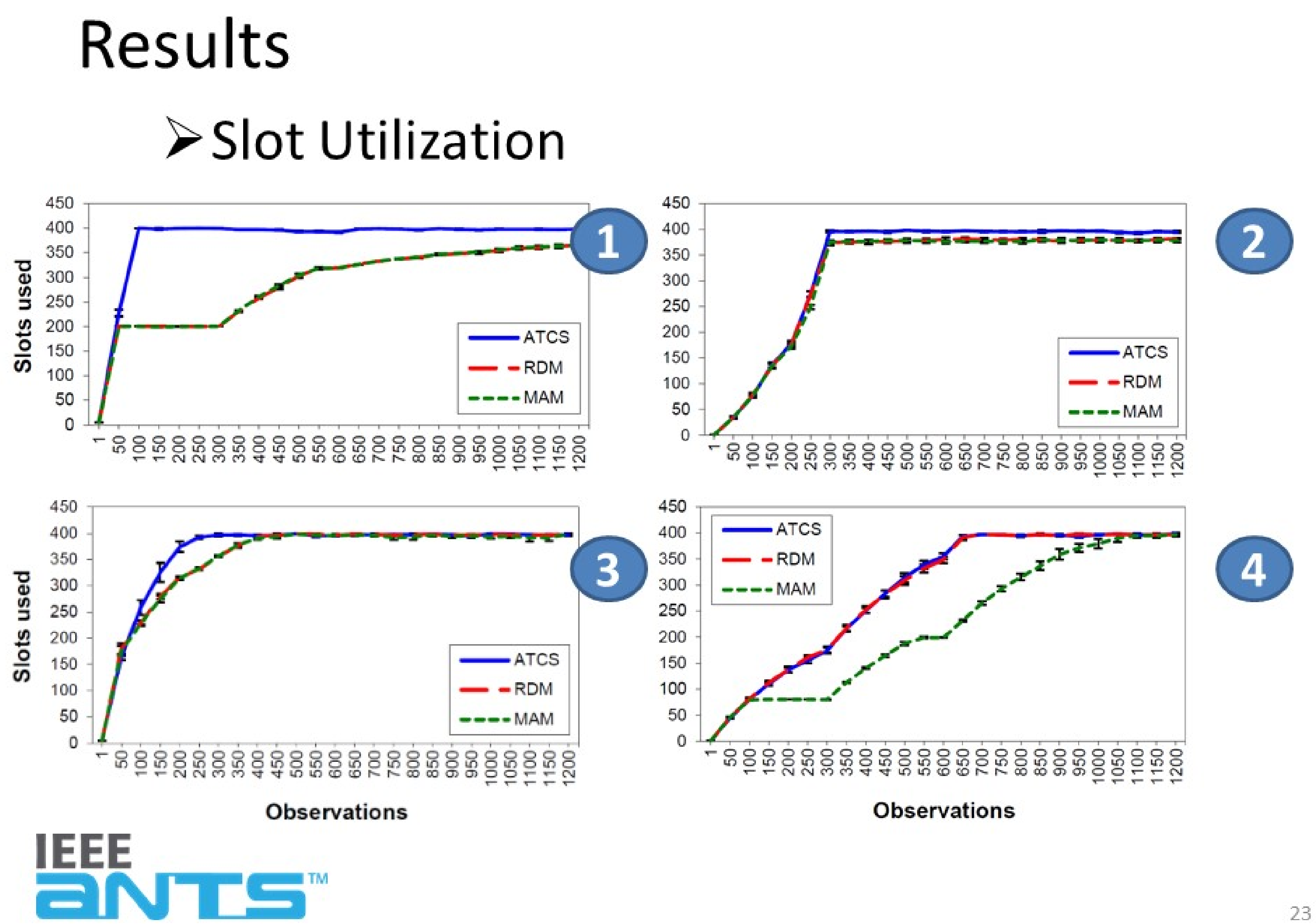


Fig. 23.

−− > **PAPER TEXT EXTRACT**:

"In all scenarios, the following performance metrics were evaluated:

- Blocking – computed unestablished lightpaths;
- Slots utilization – the effective slot utilization; and
- Established lightpaths – number of established lightpaths."

"In Figure 23.1 (scenario 1), MAM and RDM models show similar behavior in terms of slot utilization. This is because the traffic class with highest priority was generated first with lowest arrival times. In this scenario, the ATCS model presents greater slots utilization by allowing “low-to-high" loans."

"In Figure 23.2 (scenario 2) the evaluated models show a similar behavior in the use of slots. This is because the highest priority classes of requests are being generated delayed, despite the interarrival times are lower."

"In Figure 23.3 (scenario 3) is possible to observe that the evaluated BAM models show a similar behavior in term of slots utilization. This is because the highest priority classes of requests are being first generated but with longer inter-arrivals time. In this scenario, the ATCS model presents at the beginning of observation, the greater use of slots allowed by "low to high" loans."

"Figure 23.4 (scenario 4) shows slot utilization per BAM. It is possible to observe that the ATCS and RDM models show a similar behavior in terms of slot utilization. This occurs because the highest priority class requests are being generated at last with higher inter arrival times. In this scenario, the ATCS and RDM models present increasing slot utilization after simulation's initial phase by "top down" loans enabled, which do not occur with the MAM model."

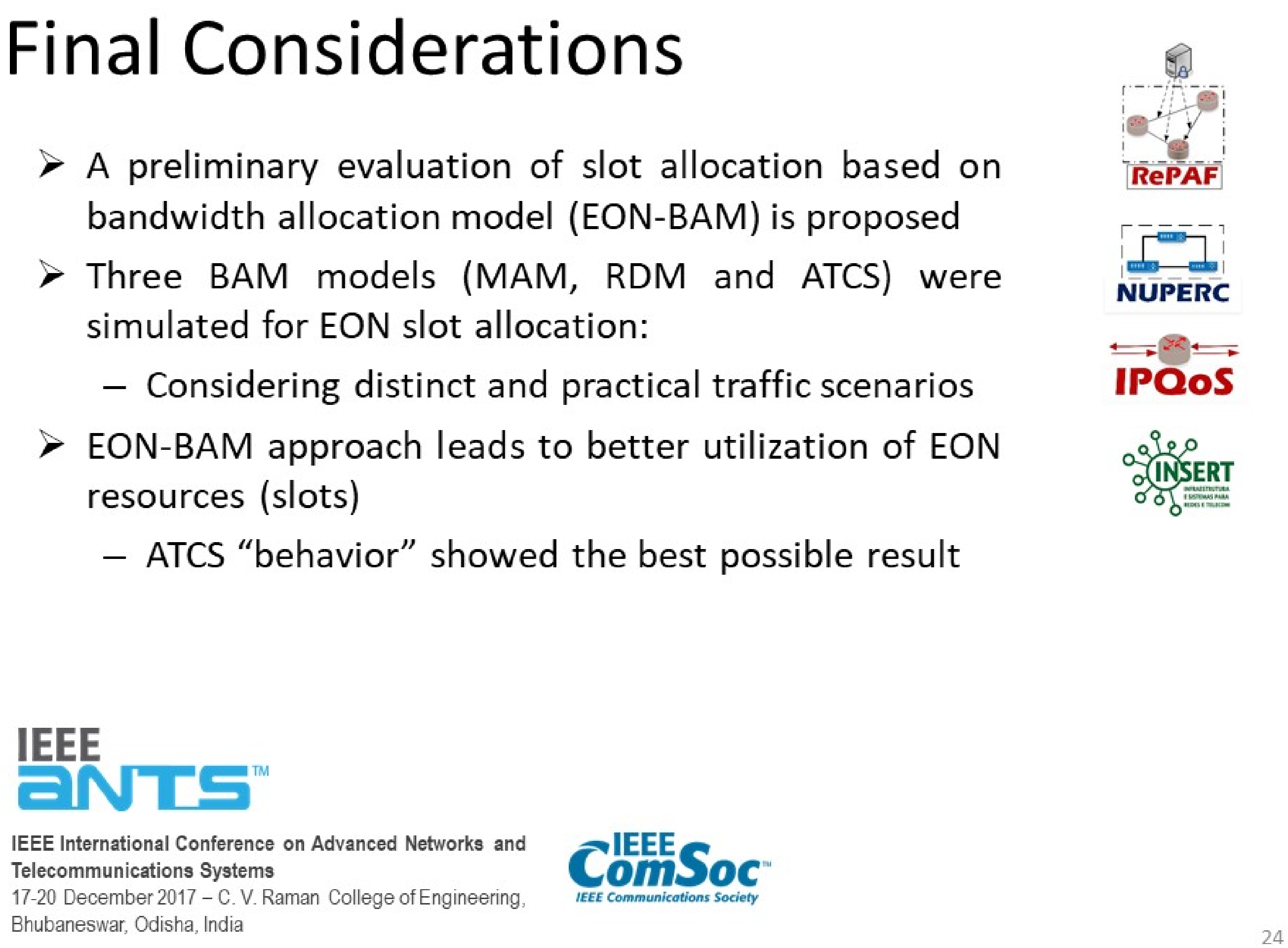


Fig. 24.

−− > **PAPER TEXT EXTRACT**:

"Three BAMs (MAM, RDM and AllocTC-Sharing) were configured and simulated for slot allocation with distinct and practical traffic scenarios. The traffic scenarios simulated tried to reflect the variability of input traffic configuration currently existing on EON.

In general, the consistency of results in different traffic scenarios indicates the potential applicability, flexibility and, consequently, better utilization of EON's resource when EON-BAM is used.

When we consider the alternatives among the evaluated BAM models for EON-BAM, the AllocTC-Sharing "behavior" shows the best possible result. It is observed that this model deals with all traffic profiles and "adapts" itself on a dynamic and opportunistic way, sharing slots among high priority and low priority traffic classes. AllocTC-Sharing configuration for EON-BAM leads to a better resource utilization when compared with other BAM models. It is also important to mention that this is a preliminary result and conclusion is focused on resource utilization only. In effect, in case AllocTC-Sharing is configured for EON-BAM, managers and network polices must consider the fact that "slot devolution" will occur. As such, the application and services mapping to the configured traffic classes (TCs) must consider the fact that devolution will eventually occur, and applications mapped to high priority classes should support an "elastic" behavior"

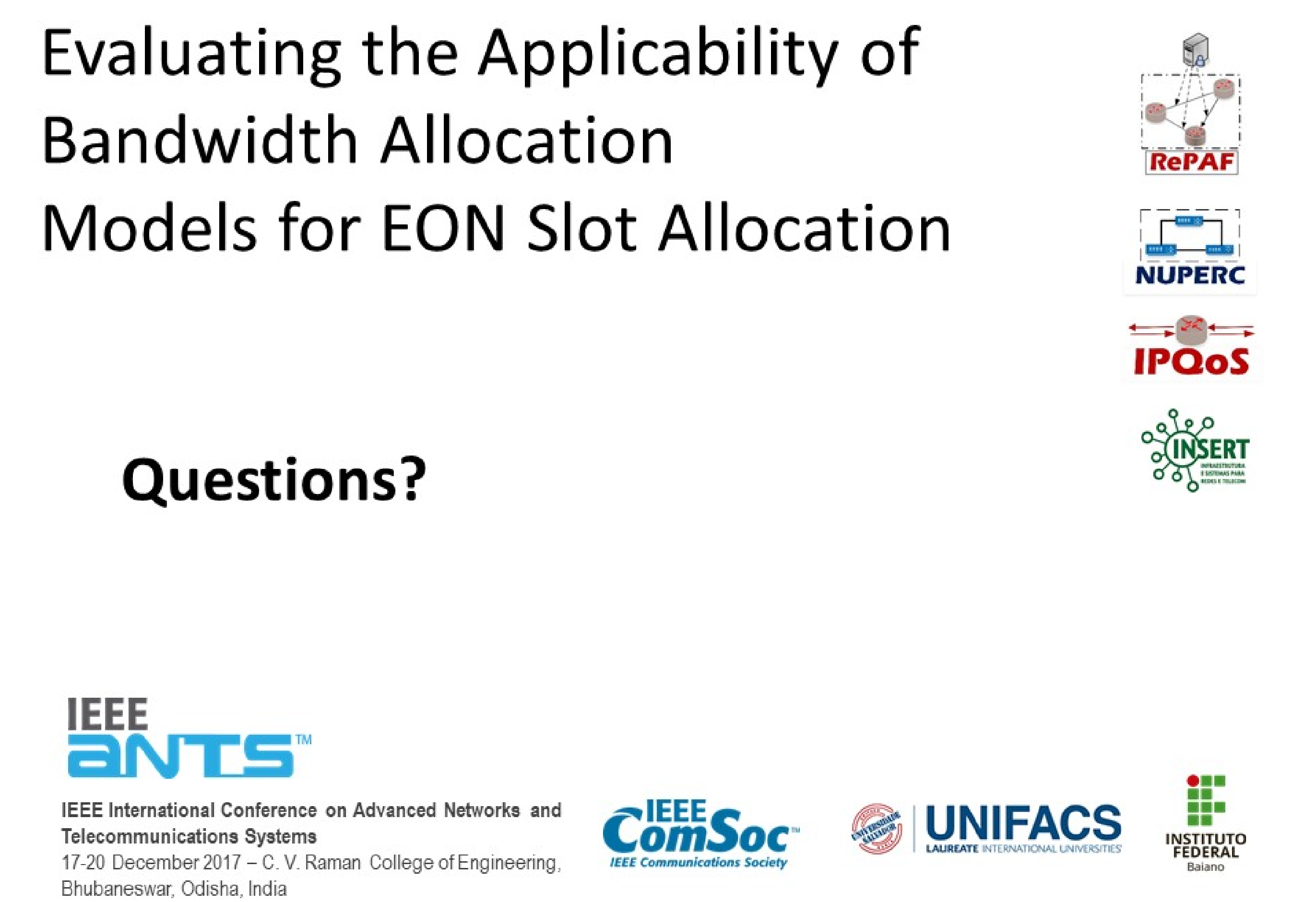


Fig. 25.

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1) RePAF Research Project: Dynamic and Cognitive Resource Allocation Model and Framework for MPLS, Elastic Optical Network (EON), Internet of Things (IoT) and Network Function Virtualization (NFV)

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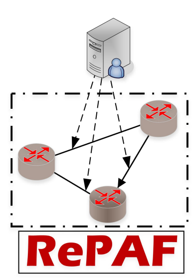

Fig. 26.

2) CNPQ Research Grant - Project "Transporte de Tráfego Multisrviço através de Redes Óoticas Elásticas sob Restrições de Camada Física":

Fig. 27.

3) Salvador University - UNIFACS - PPGCOMP Research Fund Allocation

Fig. 28.

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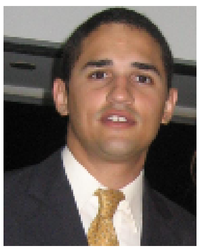

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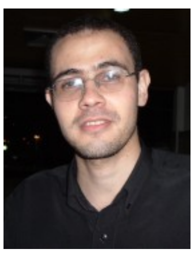

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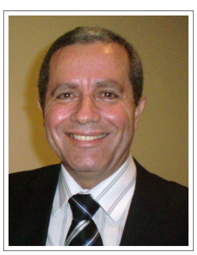

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