Photonic Devices for Next-Generation Broadband Fiber Access Networks

Leonid G. Kazovsky, She-Hwa Yen , Shing-Wa Wong
Department of Electrical Engineering, Stanford University CA, USA 94305

ABSTRACT

Next-generation optical access networks will deliver substantial benefits to consumers including a dedicated high-QoS access to bit rates of hundreds of Megabits per second. They must include the following features such as: reduced total cost of ownership, higher reliability, lower energy consumption, better flexibility and efficiency. This paper will describe recent progress and technology toward that goal using novel photonic devices

Keywords: Fiber access network, PON, MEMS, sleep mode.

1. INTRODUCTION

To meet the ever-increasing bandwidth demands of broadband access, optical networks are considered to be the best long–term solution for "last mile", especially when future bandwidth-demanding services such as triple play are provided. Currently gigabit-rate passive optical networks (PONs) such as EPON or GPON are widely deployed. Current PONs have acquired huge volume of residential and business customers, and their deployments are growing rapidly worldwide. However as network demands keep growing, it is becoming increasingly clear that current PON systems have serious problems including insufficient bandwidth, security issues and inefficient energy consumption[1][2]. In order to solve these issues, new architecture and technologies which can gracefully evolve over the existing infrastructure would be necessary. The first part of this article reviews the current challenges of broadband fiber access network. The second part of this article will show the possible solutions to mitigate such challenges. Moreover the solutions add more intelligence and more powerful functions into PONs system while still providing energy-cost efficiency.

2. REQUIREMENTS FOR NEXT GENERATION FIBER ACCESS NETWORK

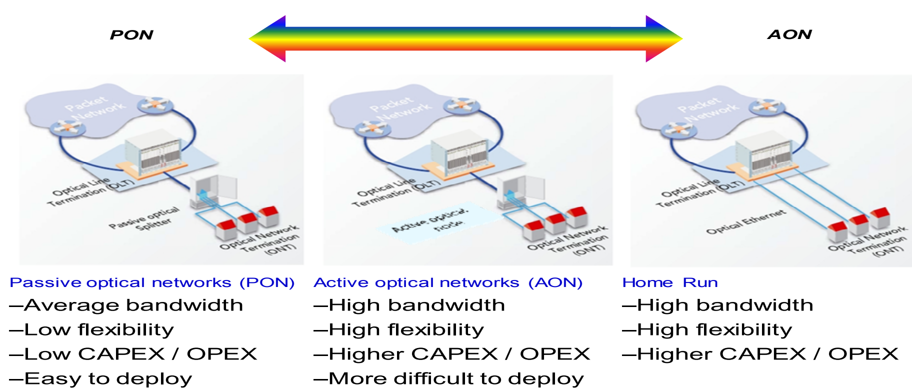


Fig.1 Optical Access Network Technology

To satisfy these bandwidth demands, optical access networks such as Passive Optical Networks (PONs) and active optical networks (AON) are being deployed by many service providers worldwide. Fig.1 shows the basic architecture for both technologies. A number of Passive Optical Networks (PONs) have been standardized (APON, BPON, GPON, and EPON) to provide broadband access service. These networks employ Time Division Multiplexing (TDM) technique and

Broadband Access Communication Technologies V, edited by Benjamin Dingel, Raj Jain, Katsutoshi Tsukamoto,
Proc. of SPIE Vol. 7958, 795802 · © 2011 SPIE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.879495

a passive remote node (RN) to achieve cost-effectiveness, and have been widely accepted as the current-generation optical access solutions. On the other hand AONs use active remote node (ex: switches) to distribute the data to users and the bandwidth is not shared like PON case. PON has its own advantage in terms of simple architecture and low cost. Although PON enables significant bandwidth boost from copper-based access networks, its capacity will be exhausted eventually as more bandwidth-hungry applications, such as HDTV and 3D-video, become available in the near future. Moreover, operators have huge economic interests to pursue access architectures that further reduce their capital and operational expenditure requirements by consolidating the number of access central office (CO) sites. To fit the incoming requests from users and improve the performance of operation, the goals for next generation optical access network should be as follow: **(1) Graceful evolution to WDM (2) Improve resilience – protection and security. (3) Flexible and adaptive PONs (4) Energy efficiency**. The following sections will describe the candidate solutions and required photonic components.

2.1 Graceful evolution to WDM

Optical access networks will facilitate graceful evolution to higher bandwidth and data rates. Rather than replacing existing services, new (such as 10Gbps or CWDM signals) and existing signals must co-exist over the same fiber infrastructure. To achieve graceful evolution from current to next generation optical access networks, service providers can choose to deploy prearranged network equipment to launch the upgrade signal at new wavelengths or overlay new signal using sub-carrier multiplexing (SCM). However consider about long term capacity demand and scalability of the network, flexible and dynamic bandwidth access network architecture is required. We developed a novel architecture, SUCCESS DWA (dynamic wavelength allocation), which has the ability provides a highly scalable solution to hybrid TDM/WDM PONs and achieves a high statistical multiplexing gain.

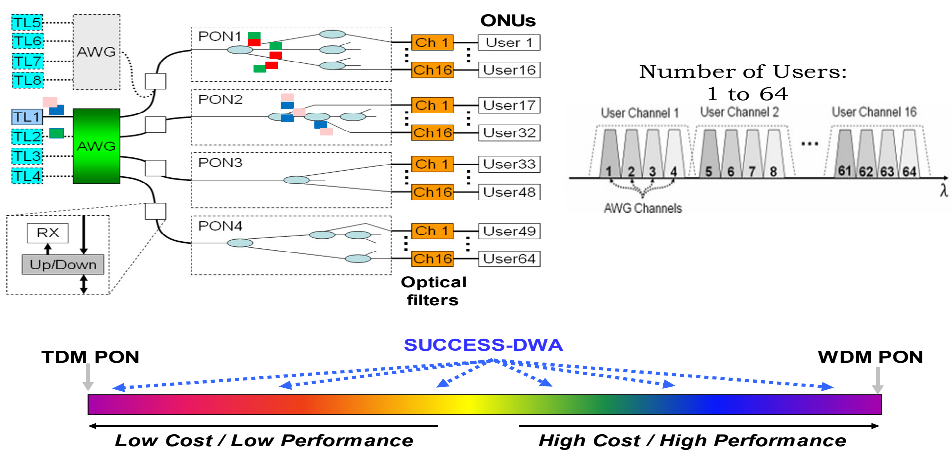


Fig.2 SUCCESS-DWA architecture

Fig.2 shows the basic architecture of SUCCESS-DWA PON. The key components of the system are the fast tuneable lasers (TLs), cyclic AWGs, and thin-film WDM filters. The field-deployed infrastructure is compatible with TDM-PONs. a cyclic AWG multiplexes the TLs and routes the TL outputs to physical PONs, depending on the wavelength. Each ONU within a single PON contains a unique fixed-wavelength filter and a burst-mode receiver. The key is that the passband of the ONU filter entirely encompasses the free spectral range of the AWG TL can individually address any ONU across separate physical PONs at any given time; this results in better statistical multiplexing gain than that of TDM-PONs. For future TDM PONs and DWA PONs high speed burst mode receiver is a key technology. Since the requirement for level and clock recovery are getting stringent.

2.2 Improve resilience

Current fiber access networks, due to their passive nature, lack the mechanisms to detect and counter malicious network attacks such as laser jamming, tapping, and masquerading. A fiber access network can effectively protect itself from these attacks if and only if it can support both (A) optical signal monitoring and (B) counter network attacks. In recent research activities, there have been novel approaches to address these problems.
(A) ONU authentication: ONU authentication functions must be included to identify unauthorized ONUs that attempt to communicate or interfere with network service. Previous solutions such as loop back modulation scheme and In-band

optical frequency domain reflectometry (OFDR) has limitation. We have proposed an optical signature detector approach (Fig.3). An ASE source on the 1550nm band is multiplexed with the downstream data. The ASE passes through an AWG thereby giving separate frequency components at the output. One frequency component is required per upstream line. Each output feeds one input line to the switching block. The output of the switching block then contains reflected wavelengths for the control signals which were low. Hence, the wavelengths present in the reverse path from the AWG are the ones corresponding to the ONUs which did not transmit any data at that point of time. This control signal is combined with the upstream data and sent to the OLT. The OLT can then demultiplex the data and the control signal and further demultiplex the various frequency components of the control signal to find out the ONUs that transmitted data during that time.

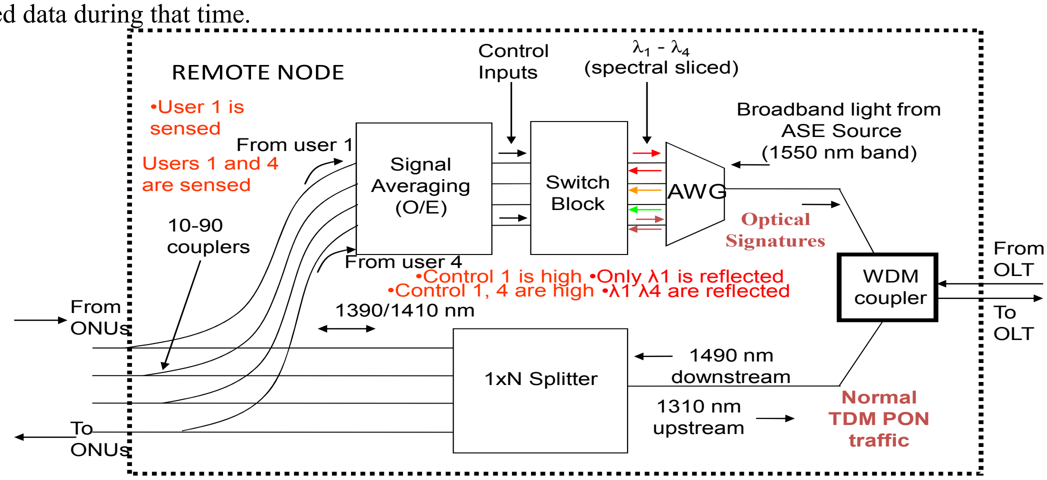


Fig.3 DOS Identifier

(B) Optical countermeasure: optical countermeasure is necessary to block an identified intrusive user from gaining fiber access. In instances such as a malicious attack or even only a malfunction ONU, countermeasure is the only mean that can protect the operation of other normal ONUs. An effective countermeasure system based on a passive and remotely configurable device was proposed in [3] (Fig.4). The proof-of-concept system is realized using a specialty fiber that is concatenated with carbon-coated TeO_2 segments that are susceptible to high laser power. The specialty fiber acts as an optical fuse circuit, and the system uses this property to expel malicious users from the network. The implementation, illustrated in Fig. 4, employs thin film filters (TFF) and array waveguide grating (AWG) to achieve wavelength multiplexing and control signal processing functions, respectively. To perform a counter measuring operation, OLT will send a high power control wavelength toward the device, which then routes the control signal to the identified branch and activates the fuse circuit. The response time of the fuse circuit is measured to be approximately 30 µs. One benefit of this architecture is the device remains passive and does not demand electrical power to activate the fuse circuit.

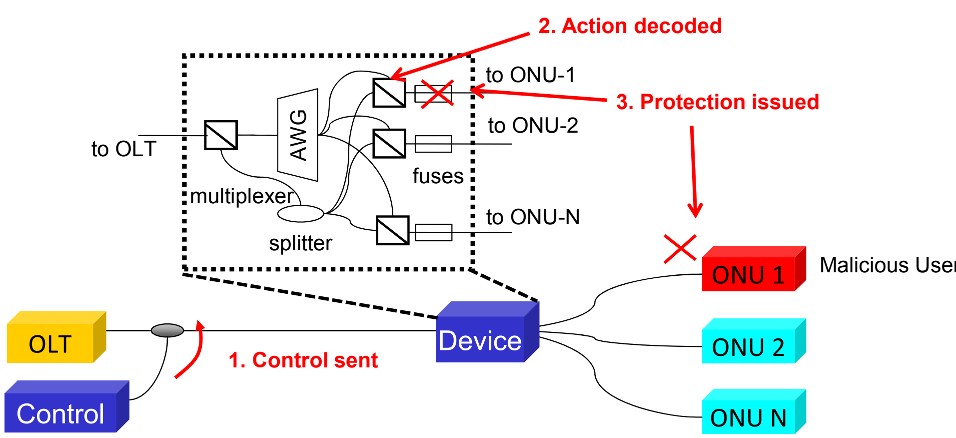
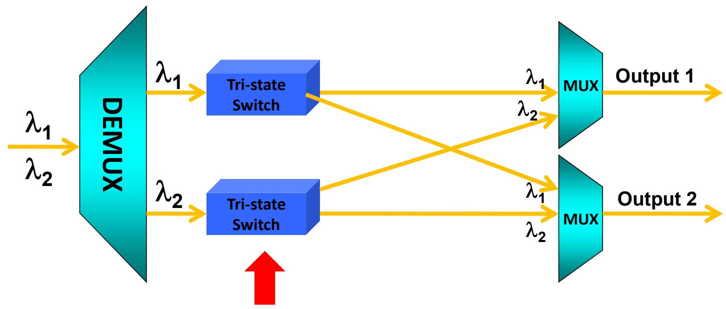


Fig.4 Node architecture of optical countermeasure

2.3 Flexible and adaptive PONs

Due to their TDM operation and to share the feeder fiber, current PONs only have static configuration such as fixed power and wavelength assignment. Reconfigurable power/wavelength routers are important for next-generation optical access networks. Reconfigurable router can allow flexible distribution of optical power and wavelength to enable greater reach-user scalability. The key challenge in building these reconfigurable routers is keeping the device passive. Fig. 5 shows the concept of such reconfigurable router.



Tri-state Switch	State One	State Two	State Three
Port One	100%	0%	50%
Port Two	0%	100%	50%

Fig.5 Tri-state example for reconfigurable router

Each tri-state switch serves as optical power routing module and can be configured to three states: pass light through specific switch output port or block one of the switch output port, or pass through both ports. Combining with the DEMUX/MUX module, we can achieve flexible wavelength/power combination at Output1/Output2. In PONs, the passive splitter can be replaced by cascading several basic units. While this mechanism is certainly more restrictive in terms of achievable coupling ratios when compared to analog tuners, it has the advantage of being nearly as energy efficient as a passive component if the switches have non-volatile feature. In order to realize the non-volatile tri-state switch, two candidate technologies are introduced[4]. One is MEMs based architecture; the other is transition metal oxide based device. In the MEMs solution, two bi-stable switches are aligned along the same axis. One of the bi-stable mirrors is coated with a 50/50 reflector and the other with a 100% reflector. Together, tri-states are achievable via the combination of the two states in each switch. In order to realize the non-volatile tri-state switch, two candidate technologies are introduced. One is MEMs based architecture; the other is transition metal oxide based device. In the MEMs solution, two bi-stable switches are aligned along the same axis. One of the bi-stable mirrors is coated with a 50/50 reflector and the other with a 100% reflector. Together, tri-states are achievable via the combination of the two states in each switch (Fig.6a). Fig.6b shows the energy-displacement diagram of spring in proposed MEMs device. It has two convex low energy points which can be used for bi-stable latching mechanism. Another proposed solution is to use transition metal oxide to form the switch. In such device the drift of oxygen vacancy will change the resistance and absorption coefficient.

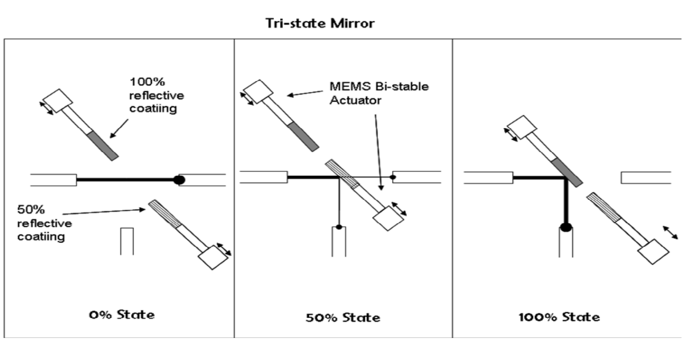


Fig.6a Tri-state MEMs

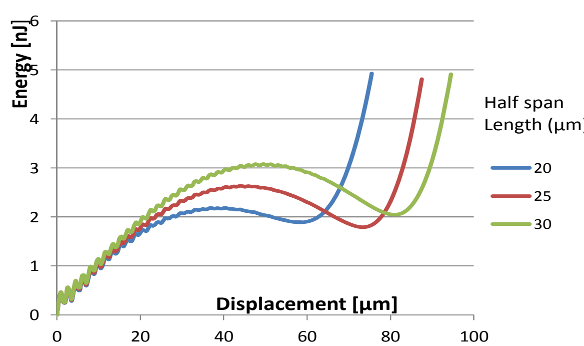


Fig.6b latching property of tri-state MEMs

Another proposed solution is to use transition metal oxide to form the switch (Fig.7a). In such device the drift of oxygen vacancy will change the resistance and absorption coefficient. The measurement result shows (1) the resistance of the crystals changed according to the applied voltage (2) the color of the material near the right down corner has changed from dark blue to transparent after the voltage is removed (Fig.7c,d). It can stay in this state without supplying voltage. After reversing back the polarity of the supply voltage, the color returns to its original state. The change of electrical and optical property comes from the drift of oxygen motion.

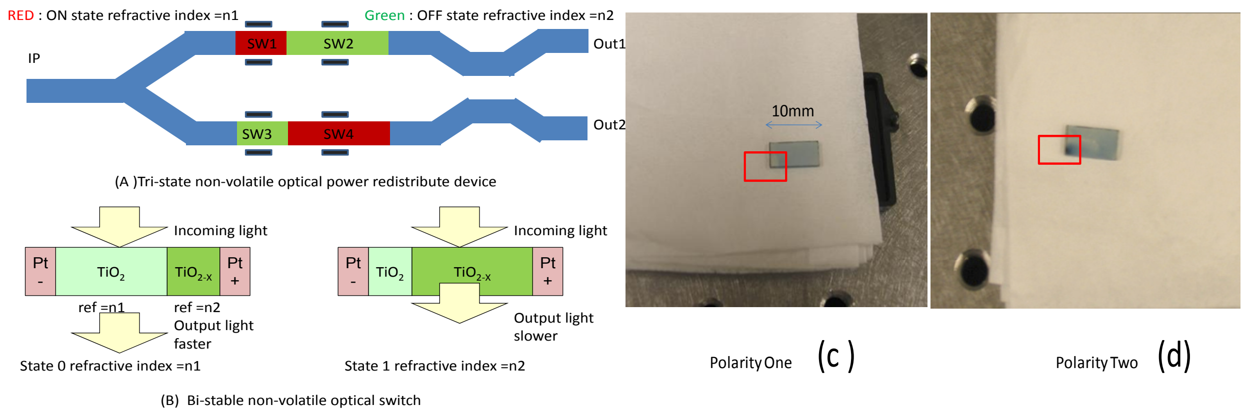


Fig.7 transition metal oxide based switch (a),(b) MZI based tri-state switch, (c)(d) non-volatile change of optical property.

2.4 Energy efficiency

Telecommunication equipments account for at least 8% of U.S. energy consumption in the year of 2007. Among all network segments, broadband access network dominates and consumes more than 75% of energy consumption by all telecommunication equipments today. In wired part of broadband access networks, it has been observed that the end-user devices consume a significant portion of the energy with respect to centralized equipments. The importance of lowering energy consumption of end-user devices is also recognized by the setup of the IEEE P802.3az Energy Efficient Ethernet Task Force. IEEE P802.3az proposes to reduce power consumption level of end device by reducing connection rate during light traffic use. However, there are considerably few works in lowering energy consumption of end-user devices in fiber access networks. Therefore it is important to explore the energy saving potential of employing ONU sleep mode in passive optical networks (PONs).

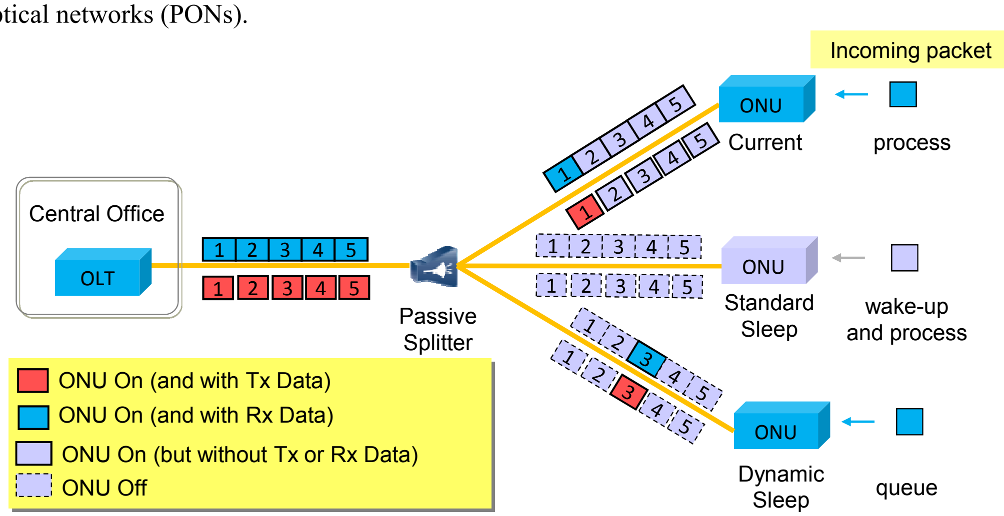


Fig.8 Energy saving using dynamic sleep mode

Recently, both ITU and IEEE bodies amend energy conserving strategies for GPON and EPON, respectively. Show in fig. 8, the standard energy conserving TDM-PON architectures puts ONU into sleep mode during little and/or no traffic usage. Proposed in [4], dynamic sleep mode further exploits idle time within the TDM traffic and puts ONU into sleep mode when the ONU is not receiving or sending data traffic. Fig. 9 illustrates a generic architecture of the energy conserving TDM-PON using sleep mode ONU. In the architecture, a mode switcher moves an ONU into sleep mode based on OLT command. The criterion for moving an ONU into sleep mode depends on the scheme employs by the OLT/ONU. With a modified version of ONU using fast burst mode CDR, we can achieve transition time (from sleep mode to active mode) less than 64ns. We also proposed just-in-time sleep control (JIT-SC) scheme preserves the characteristics of current class of dynamic bandwidth allocation (DBA) algorithms and controls while further enabling variable sleep time assignments. In JIT-SC scheme, the upstream traffic bandwidth allocation and request operations follows the ones from existing DBA.

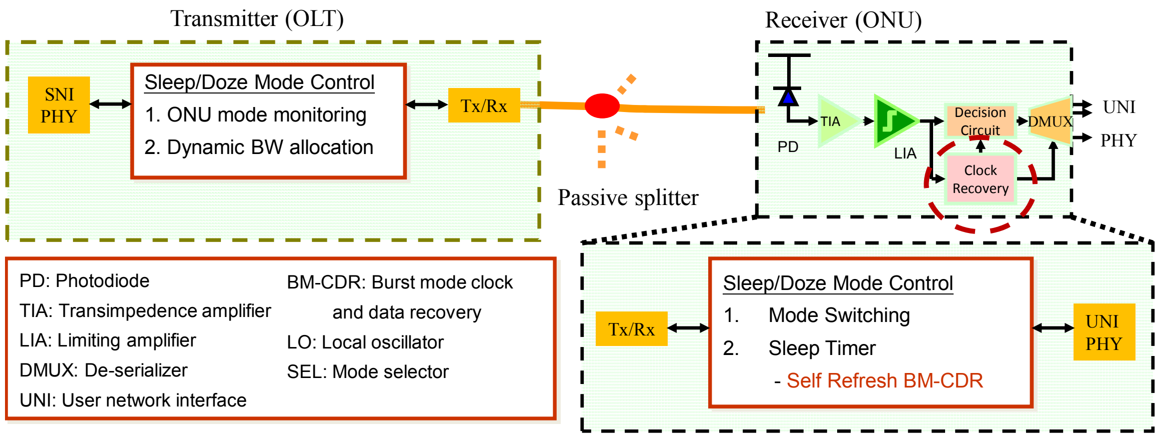


Fig.9 Proposed energy conserving TDM-PON architecture using sleep mode ONU with fast wake-up capability

3. SUMMARY

In the coming years with increasing demands for bandwidth from end users, the current architectures have to evolve to support the requirements of the future. The next generation architecture should have the following features 1: Graceful Migration to Higher Bandwidth and WDM 2: Flexible and Adaptive PONs 3: Approaching AON Functions and Flexibility 4: Better Resilience: Protection and Security 5: Energy Efficiency. In order to achieve these features intelligent photonic technologies and components such as high speed burst-mode receivers, DOS identifiers optical fuses, Quasi-Passive Reconfigurable devices (QPARs) and sleep mode ONUs.

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