DBA

In EPON & LR-PON

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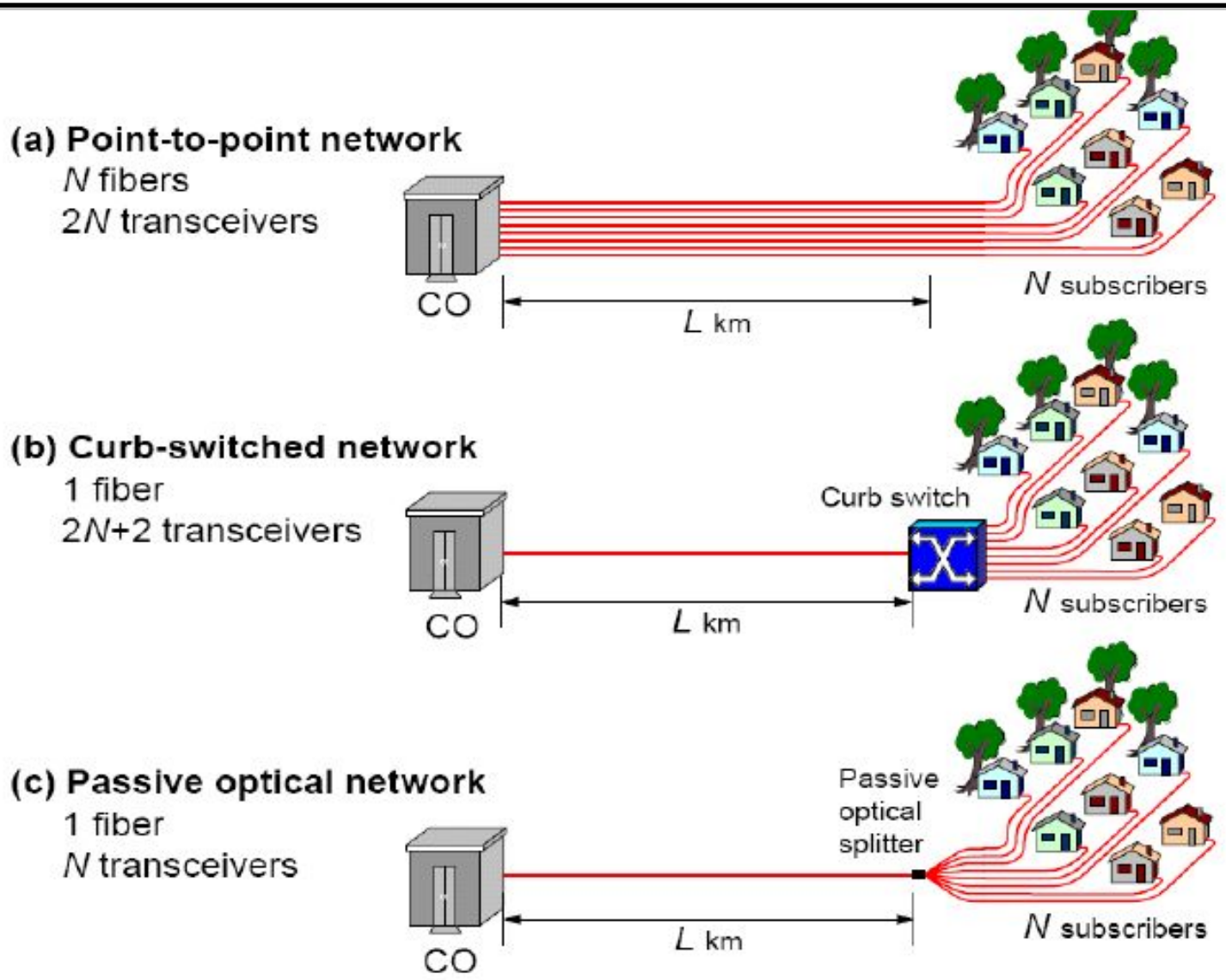
Agenda

- Introduction to Passive Optical Network
- EPON
  - MPCM
  - DBA
  - Quality of service
- Introduction to LR-PON
  - DBA

Passive Optical Network

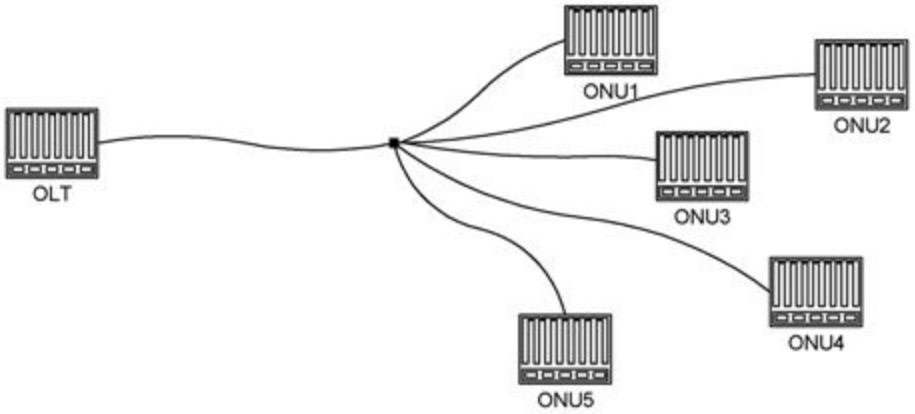
- Passive Optical Network(PON) is a point to multipoint optical network with no active element from source to destination
- Interior elements such as passive splitters, combiners and splitters
- PON technology is one of solutions for “Last Mile” problem

Passive Optical Network

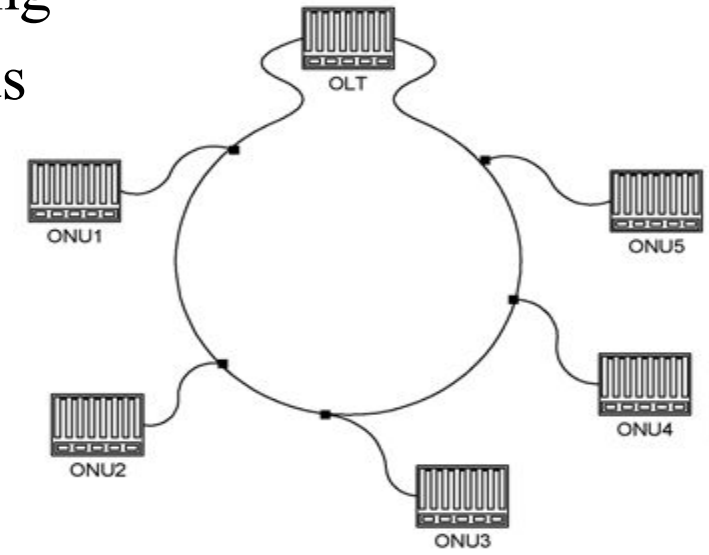


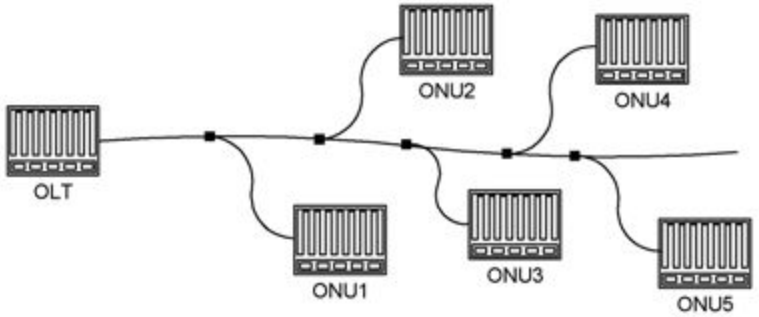
Topologies

- Optical Line Terminal(OLT)
- Optical Network Unit(ONU)
- Splitter/combiner(SC)



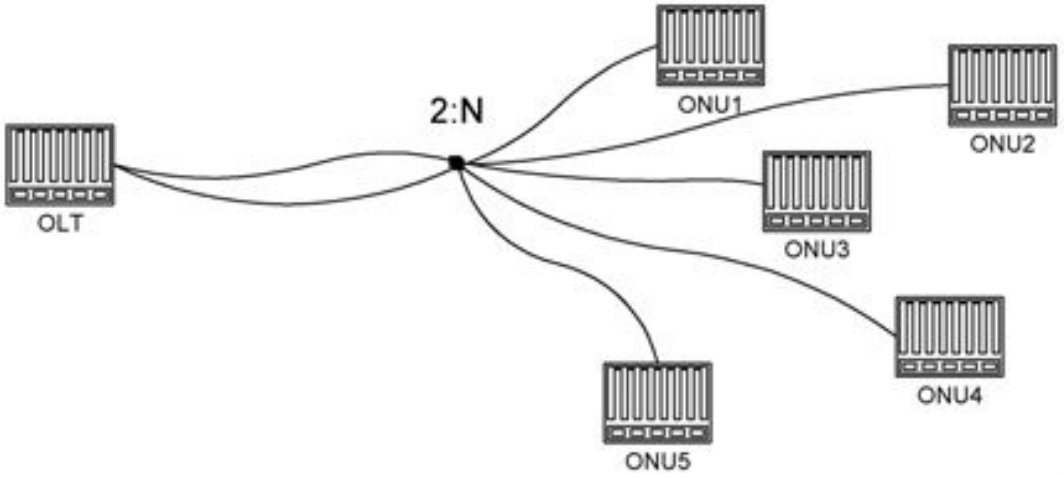
- Tree
- Ring
- Bus



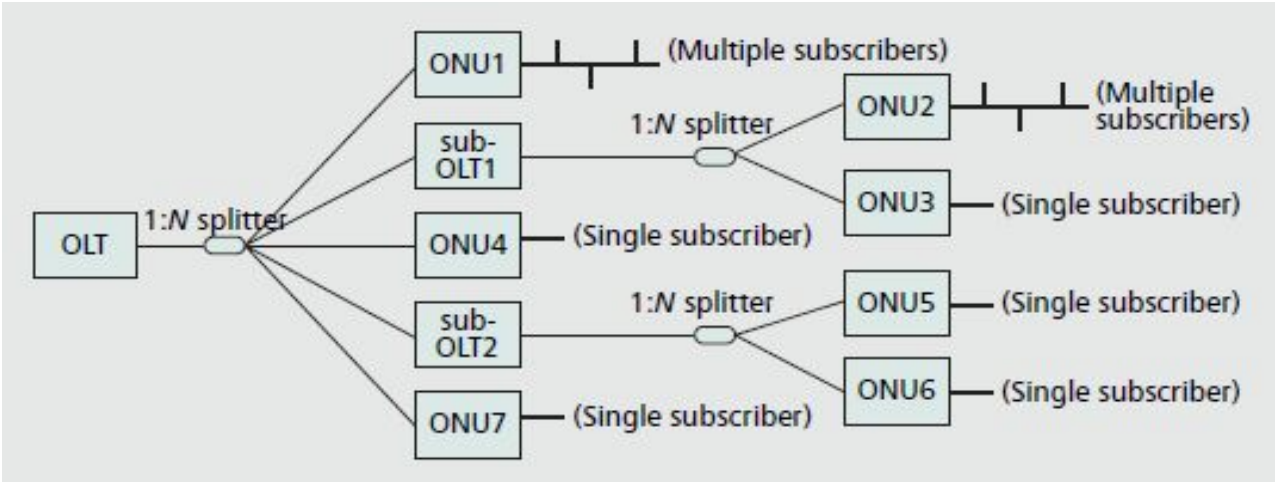


Topologies

- Redundant PON
- Two stage PON



- Data streams
  - Upstream
  - Downstream

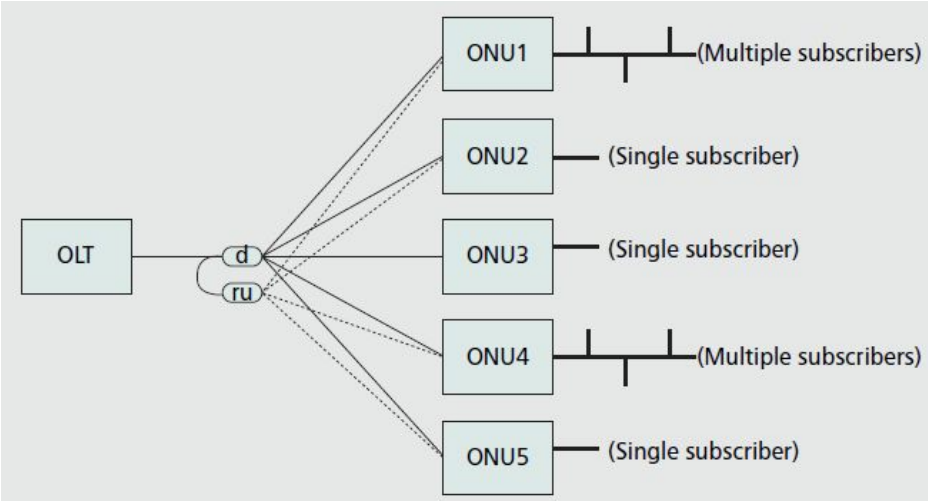


Advantages

- Longer operational range, PON operates at distance of 20 km
  - DSL range is 5.5Km
- PON minimizes fiber deployment
  - Shared channel from SC to OLT
- Provides higher bandwidth
  - Single wavelength provides at least 1 Gb/s
- Allows video broadcasting
  - In downstream direction from OLT to ONUs
- Easy upgrade to higher bitrates
  - By deploying additional wavelengths

Ethernet PON(EPON)

- PONs are categorized by their data link layer
  - APON
  - BPON
  - GPON
  - EPON



- EPON
  - Introduced by *Glen Kramer* (2001)
  - Transmits Ethernet frames
  - Ethernet frames form 90% of total traffic
    - No frame conversion

Medium Access Control- Intro

- Channel Separation
  - Space-division multiplexing, where two separate optical fibers and passive couplers are used
  - A single coupler and a single fiber for both directions with one wavelength for upstream transmission and another for downstream transmission, i.e., 1310nm and 1550 nm

- Multiple Access
  - In the upstream, multiple ONUs transmit data packets to the OLT
  - Due to the directional property of a passive combiner, data packets from an ONU can't reach to the other ONUs, conventional contention-based multiple access, e.g., CSMA/CD, doesn't suitable for EPON

Medium Access Control- Intro

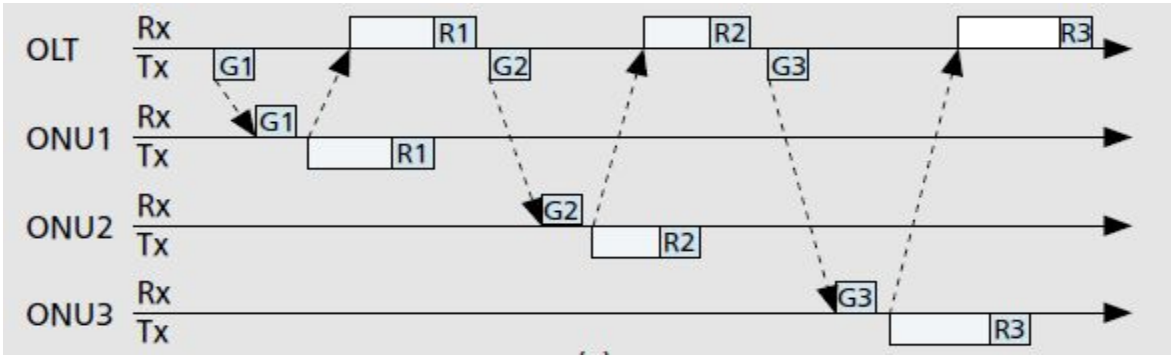
- WDM
  - Provides high bandwidth, simple to implement
  - Cost and scalability(adding new ONU problem)
- TDM
  - Each ONU has a fraction of channel bandwidth
  - Synchronization, more complicated than WDM
- CDM
  - Security
  - Inter channel interference increases by increasing number of user

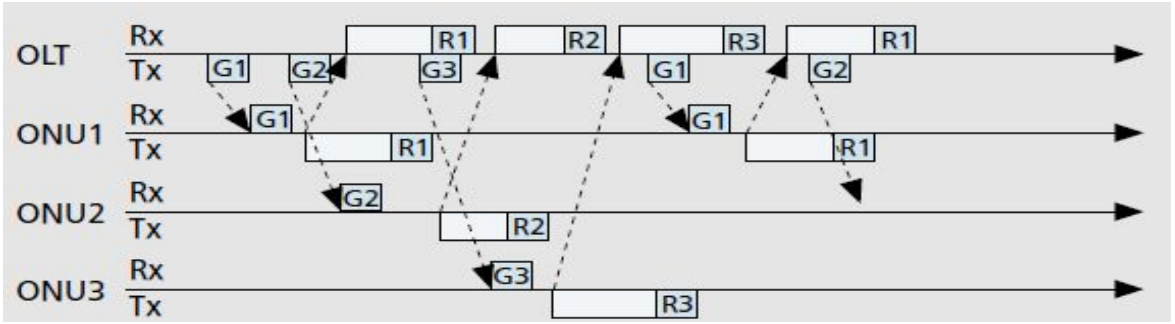
Medium Access Control- Intro

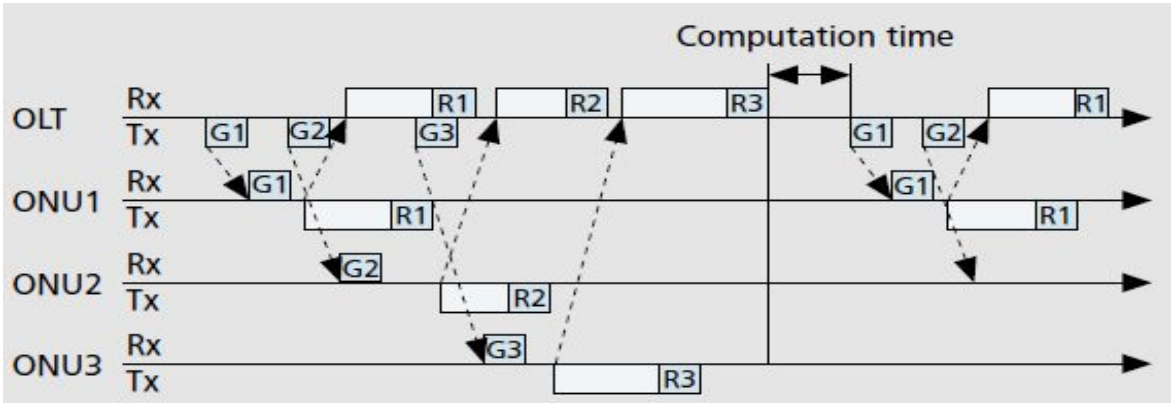
- Multipoint control protocol (MPCP)
  - Standardized by the IEEE802.3ah Ethernet in the First Mile Task Force
- Applications
  - Auto-discovery, Registration, Ranging (RTT computation)
    - Register
    - Register request
    - Register ack
  - DBA
    - Report message
      - Head of frame
      - Tail of frame
    - Gate message
      - Fixed granting
      - Gate assignment granting
      - Limited granting

Medium Access Control- Intro

- Polling policies
  - Poll & stop polling
  - Interleaved polling
  - Interleaved polling with stop.
- Scheduling modes
  - Online
  - Offline







DBA - IPACT

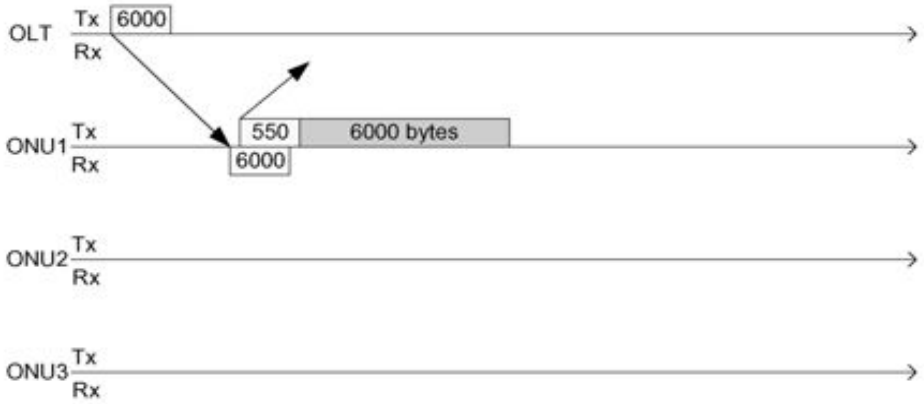
- A brief study of
  - IPACT
  - WDM IPACT
  - IGFS
  - DPA

  All of aforementioned protocols work in offline manner!

- IPACT

ONU	Bytes	RTT
1	6000	200
2	3200	170
3	1800	120

Polling Table



DBA - IPACT

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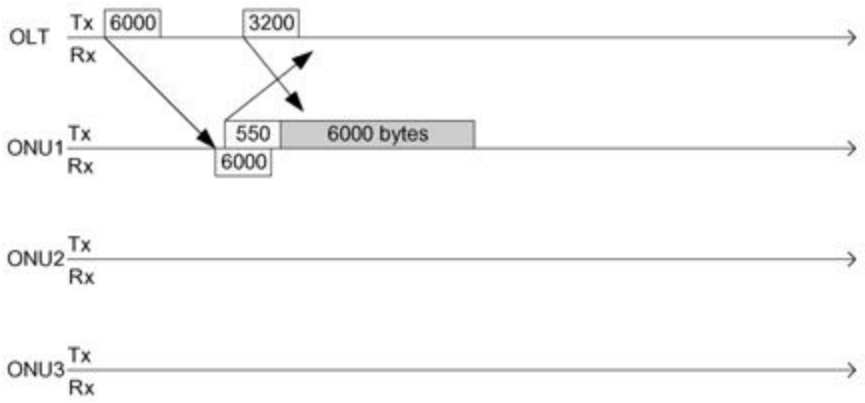

Guard time is used to:

- Avoid collision due to clock drifting
- Adjust the OLT receiver

ONU	Bytes	RTT
1	6000	200
2	3200	170
3	1800	120

ONU	Bytes	RTT
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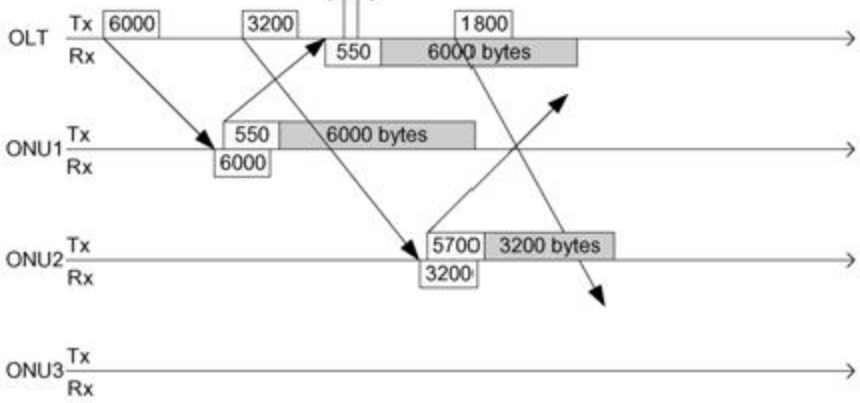
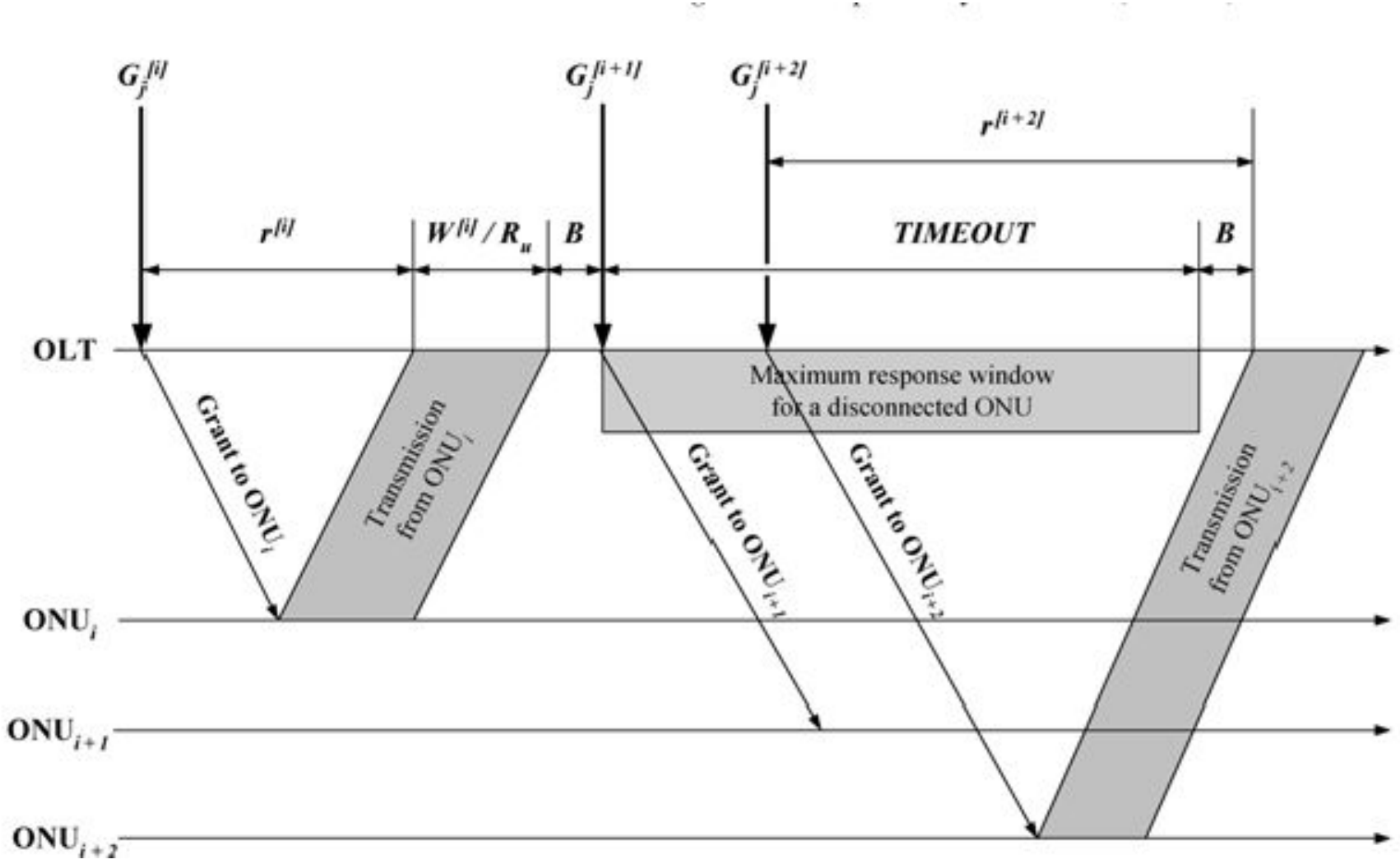


DBA - IPACT

- Gate Message Problems
  - High downstream load vs. light upstream load
  - Gate blocking behind data packets
- Solution:
  - Dedicated control channel for Gate messages

- Disconnected ONU
  - OLT can stop polling disconnected ONU in every cycle(simple solution)
  - OLT must distinguish between corrupted Report and disconnected ONU
  - OLT polls disconnected ONU less frequently

DBA - IPACT


$G_j^{[i]}$
$G_j^{[i+1]}$
$G_j^{[i+2]}$
$r^{[i+2]}$
$r^{[i]}$
$W^{[i]} / R_u$
B
TIMEOUT
B
OLT
Maximum response window for a disconnected ONU
Grant to ONU_i
Transmission from ONU_i
Grant to ONU_{i+1}
Grant to ONU_{i+2}
Transmission from ONU_{i+2}
ONU_i
ONU_{i+1}
ONU_{i+2}

DBA – WDM IPACT…

- DWM IPACT
  - Descendant of simple IPACT, where multiple wavelength are deployed I a fiber and each of them works in TDM.
  - Higher upstream bandwidth than simple IPACT
- IGFS:
  - Uses gaps that are created by dissimilarity in RTTs to utilize upstream channel
  - More efficient than WDM IPACT
- DPA
  - Divides ONUs in two subgroup with some overlap
  - OLT performs DBA for a group, while receives data from other one
  - In some cases removes channel idle time

DBA

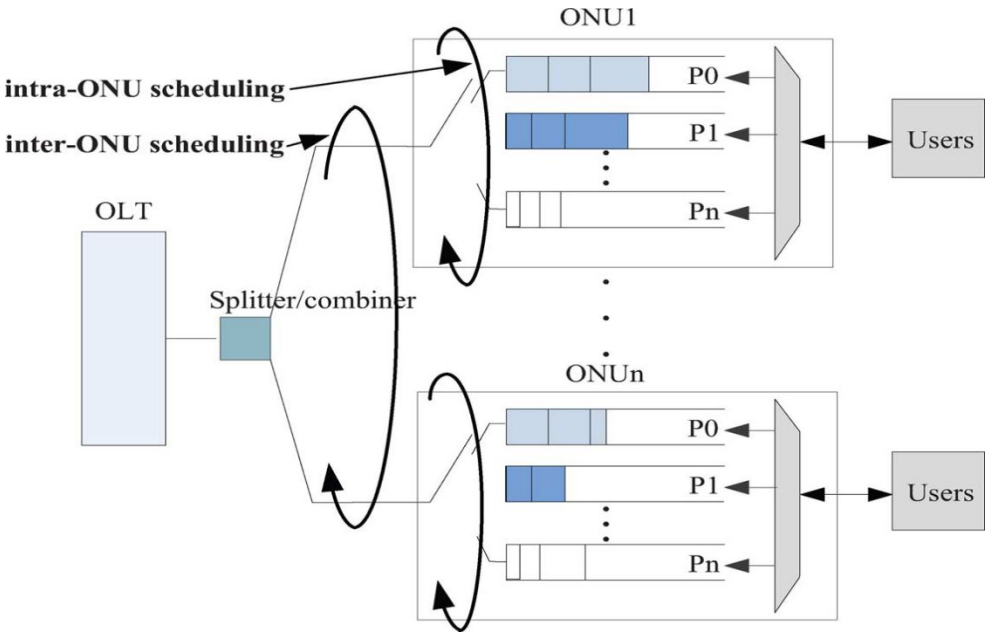
- To more utilization in EPON
  - In [1] a DBA has been proposed that employs some early allocation mechanism in which a light- loaded ONU can be scheduled instantly without waiting for the end of the scheduling cycle, but this scheme might lose efficiency at high network load
  - In [2] a DBA was introduced which predicts and schedules constant bit-rate (CBR) traffic to transmit during the idle time, but it works on a more detailed traffic classification and a certain traffic pattern

[1]: C. Assi, Y. Ye, S. Dixit, and M. Ali, "*Dynamic bandwidth allocation for quality-of-service over ethernet PONs*," IEEE J. Select. Areas Commun., vol. 21, no. 9, pp. 1467-1477, Nov. 2003.

[2]:A. Shami, X. Bai, C. Assi, and N. Ghani, "*Jitter performance in ethernet passive optical networks*," J. Lightware Technol., vol. 23, no. 4, pp. 1745-1753, Apr. 2005.

QOS in EPON

- Priority Queues
  - Expedited Forwarding(EF), CBR
  - Assured Forwarding(AF), VBR, bursty traffic
  - Best Effort(BF), not delay sensitive data, i.e., email
- Inter ONU scheduling vs. Intra ONU scheduling



QOS in EPON

- Minimum guaranteed bandwidth

$$B_i^{\mathrm{MIN}} = \frac{(T_{\mathrm{cycle}} - NT_{\mathrm{g}})\,R}{8} w_i \qquad w_i = w = \frac{1}{N}, \forall i.$$

$$B_i^R = \begin{cases} B_i^R, & \text{if } B_i^R < B_i^{\mathrm{MIN}} \\ B_i^{\mathrm{MIN}}, & \text{if } B_i^R \geq B_i^{\mathrm{MIN}} \end{cases}$$

$$B_{\mathrm{total}}^{\mathrm{EXCESS}} = \sum_{i \in M} (B_i^{\mathrm{MIN}} - B_i^R), B_i^{\mathrm{MIN}} > B_i^R$$

$$B_i^{\mathrm{EXCESS}} = \frac{B_{\mathrm{total}}^{\mathrm{EXCESS}} B_i^R}{\sum_{p \in P} B_p^R}$$

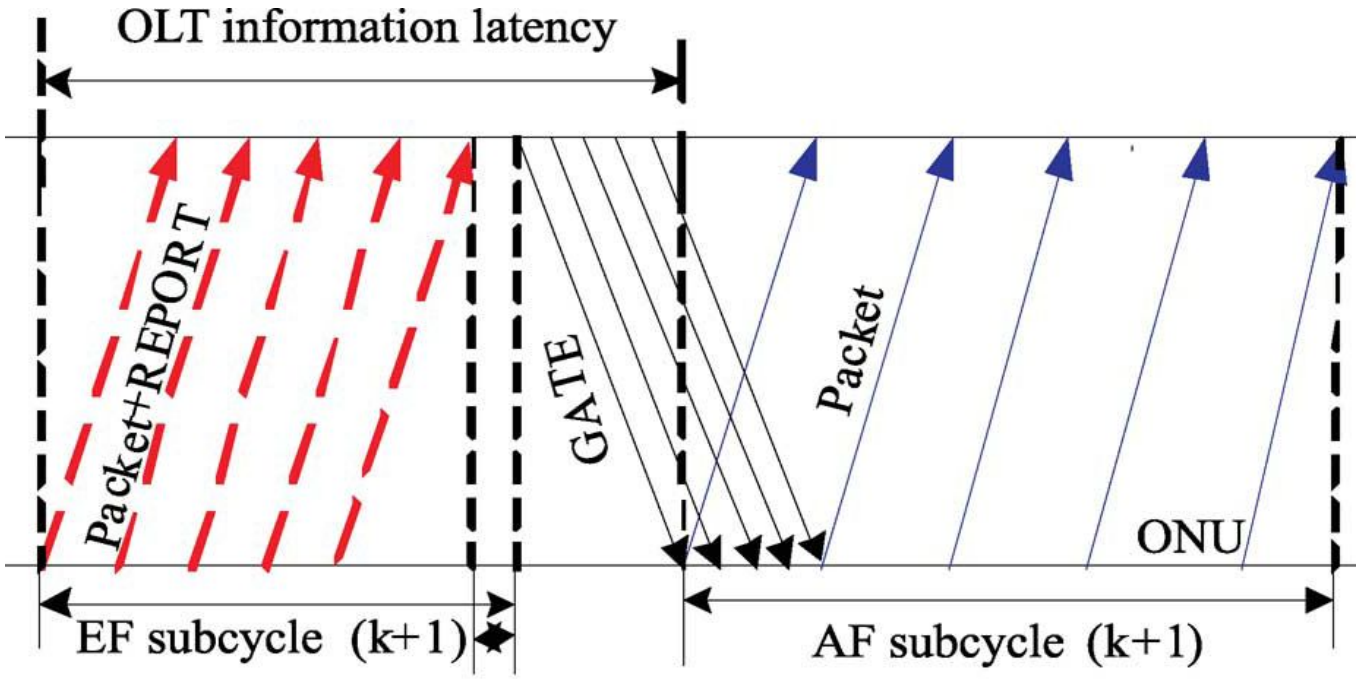
$$B_i^{\mathrm{G}} = B_i^{\mathrm{MIN}} + B_i^{\mathrm{EXCESS}}$$

QOS in EPON

- HG Protocol
  - In standard EPON algorithms, MPCP is implemented in GAR (Grant After Report) way
  - Amount of EF traffic in the system is deterministic, therefore GBR (Grant Before Report) mechanism can be used
    - It is possible to define maximum queuing time for EF packets
    - AF and BE traffic behavior is nondeterministic, standard GAR technique is used
  - HG protocol defines two subcycles, one for EF traffic(GBR mechanism) and one for AF/BE traffic(using GAR mechanism)

QOS in EPON

- OLT have to precisely predict the beginning of the next cycle in every ONU, first grants bandwidth for EF traffic, the reminder of transmission window is allocated for AF and BF



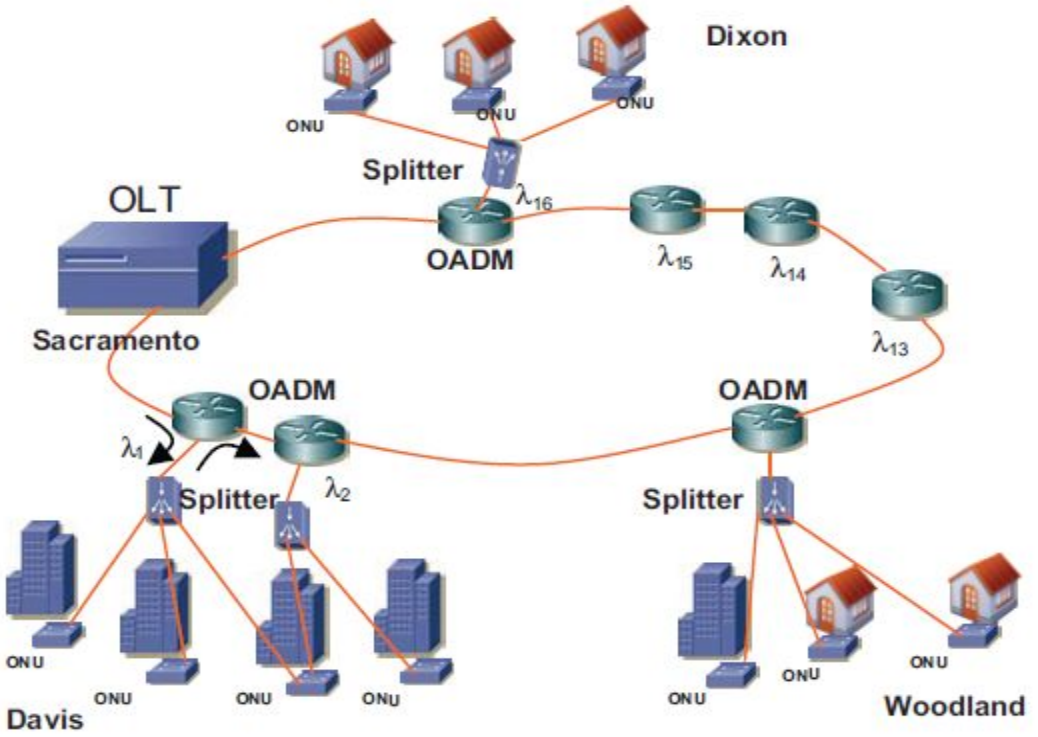
Long Reach PON

- Long-reach broadband access using passive optical network technology, Long-Reach PON (LR-PON). The strength of optical technology is its ability to displace electronics and simplify the network by combining network tiers

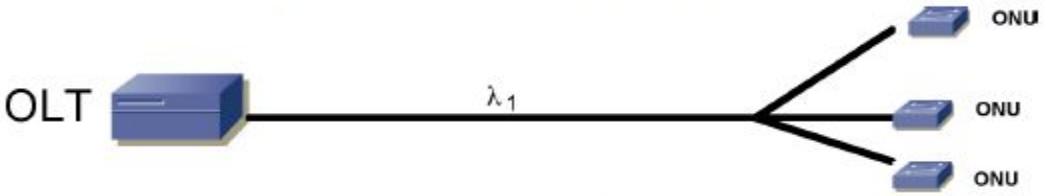
- The access and metro networks can be combined into one through the use of an extended backhaul fiber, possibly 100 km in length to incorporate protection paths and mechanisms, used with a PON

- Also called “Super PON”

Long Reach PON



(a) Long-Reach PON with a ring-and-spur structure.



(b) Logical connectivity of OLT and ONUs on the same wavelength.

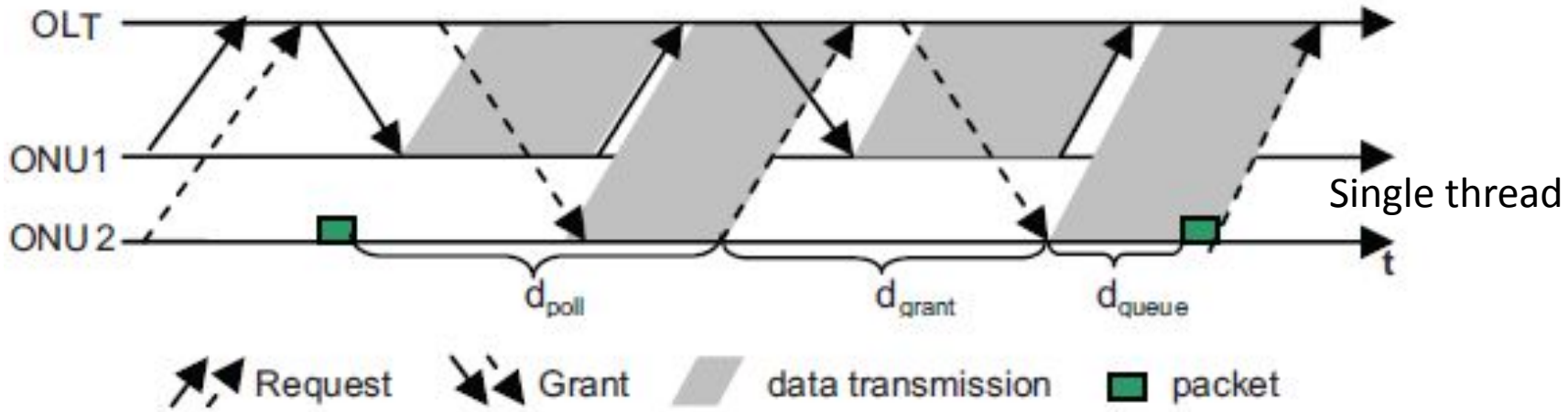
Long Reach PON

LONG-REACH PON DEMONSTRATIONS

PROJECT	BASE TYPE	REACH (KM)	#WAVELENGTHS	DOWN/UP (GBPS)	#ONUS
PLANET	APON	100	>1	2.5/0.311	2048
B.T.	GPON	135	40	2.5/1.25	2560
UNIV. CORK		100	17	10/10	4252
WE-PON		100	16	2.5/2.5	512

Multi-thread Polling- Intro

- Status-reporting mechanism

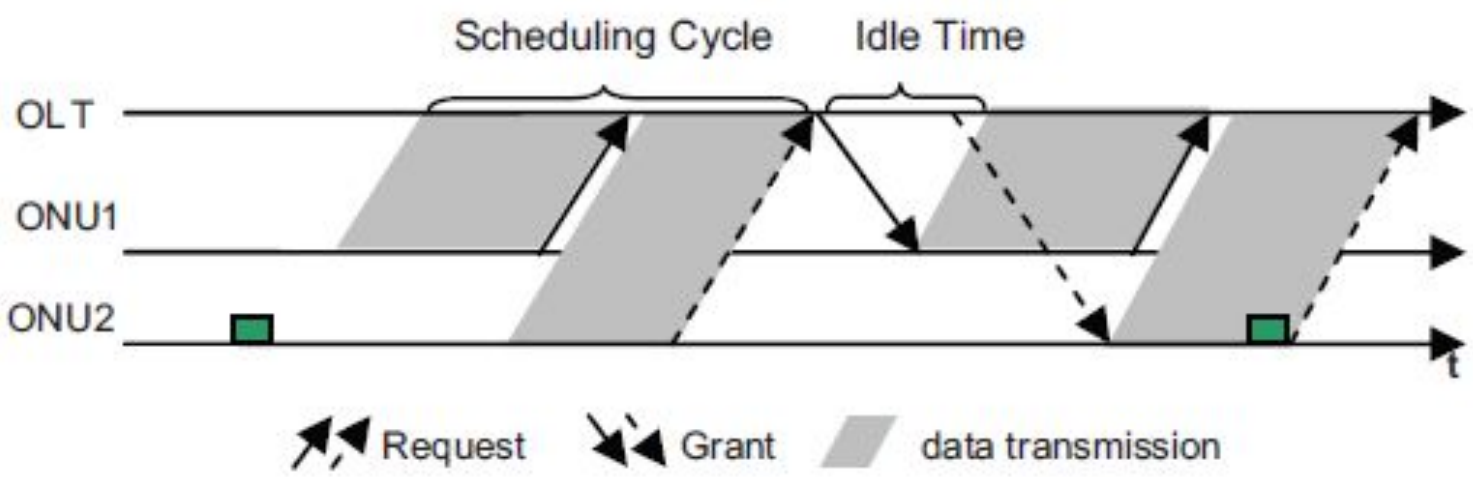


$$d = d_{poll} + d_{grant} + d_{queue}$$

$$d_{poll} = C/2$$

  - Applying this to LR-PON, we can find the impact of increased RTT on packet delay.

Multi-thread Polling- Intro



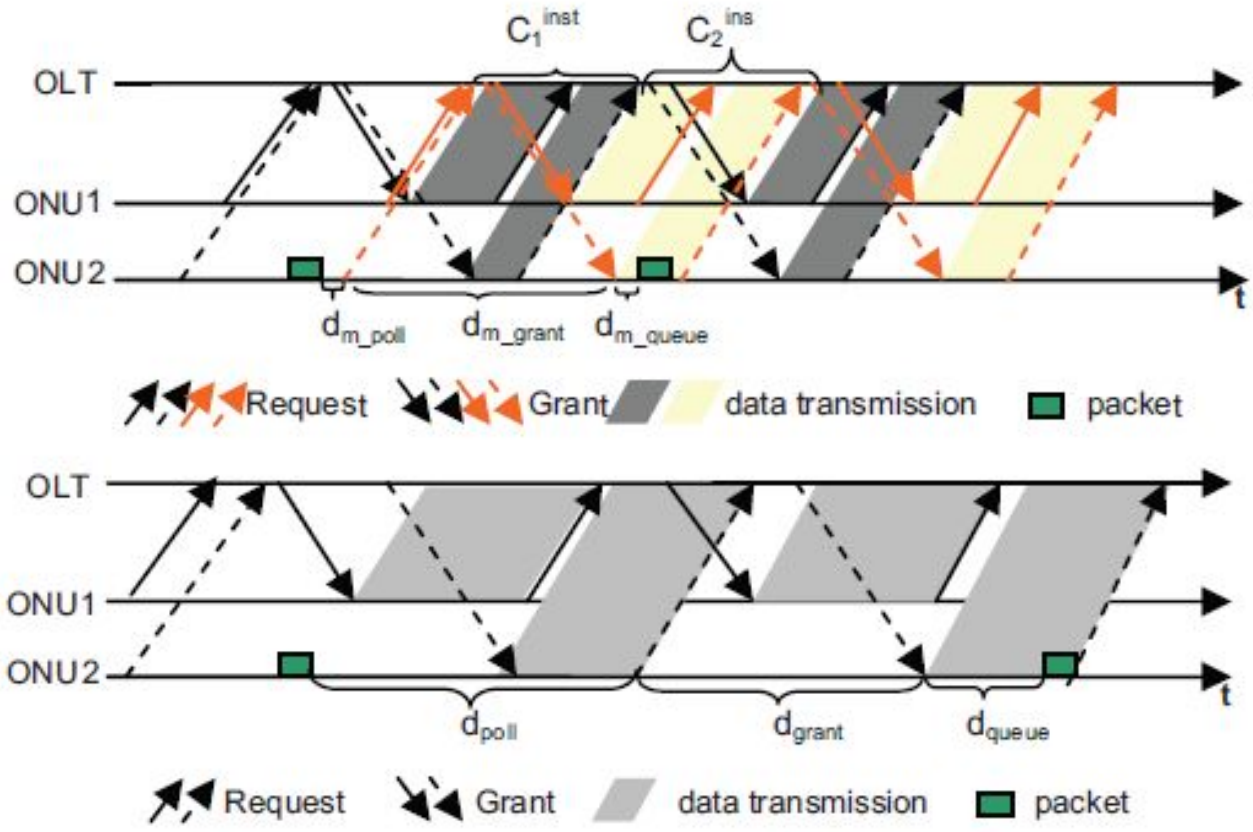
- In traditional PON, channel idle time is negligible because it is 0.1 ms with 10-km span
- LR-PON increases the idle time to 1 ms with 100 km of OLT-ONU distance, which results in 10x the idle time in traditional PON.

Multi-thread Polling- Intro

- Non-status-reporting mechanism
  - Besides the status-reporting mechanism
  - The OLT continuously allocates a small amount of extra bandwidth to each ONU
  - If the ONU has no traffic to send, it transmits idle frames during its excess allocation
  - Observing a large number of idle frames from the given ONU, the OLT reduces its bandwidth allocation else OLT increases its bandwidth allocation when observing the given ONU is not sending idle frames
  - No requirements on an ONU and no need for the control loop between OLT and ONU
  - There is no way for the OLT to know how best to assign bandwidth across several ONUs that need more bandwidth

Multi-thread Polling- Core Idea

– To achieve better performance (in terms of lower packet delay & guaranteed fairness) in a LR-PON, an idea is to allow an ONU to send its Request before the previous Gate message is received



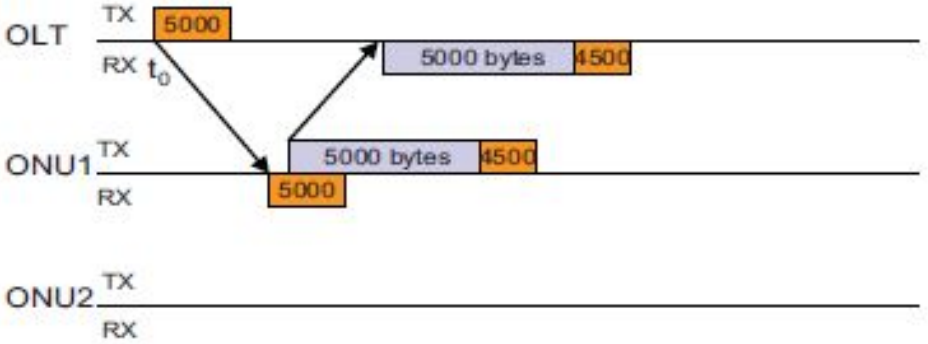
Multi-thread Polling- Intro

- The multiple-thread polling can also eliminate the idle time
- Keeps the fairness, because the transmission of Gate messages is interleaved with upstream data transmission in another polling process
- The number of threads can be increased depending on the network environment, such as
  - Hardware processing time
  - Required delay bound

Multi-thread Polling- Example

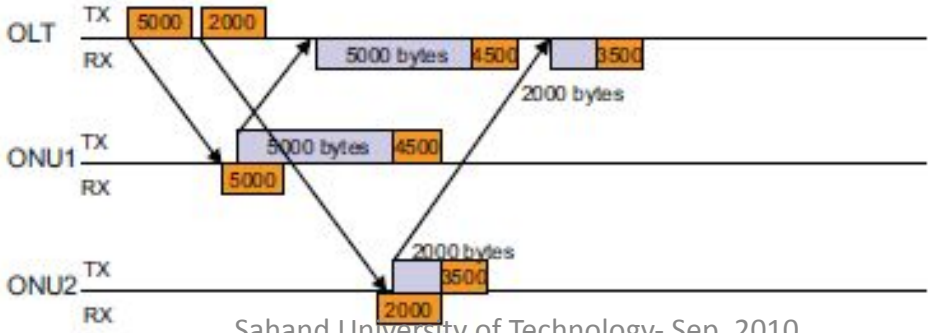
ONU	T1	T2	RTT
1	5000	4800	500
2	2000	4000	1000

ONU	T1	T2	RTT
1	4500	4800	500
2	2000	4000	1000

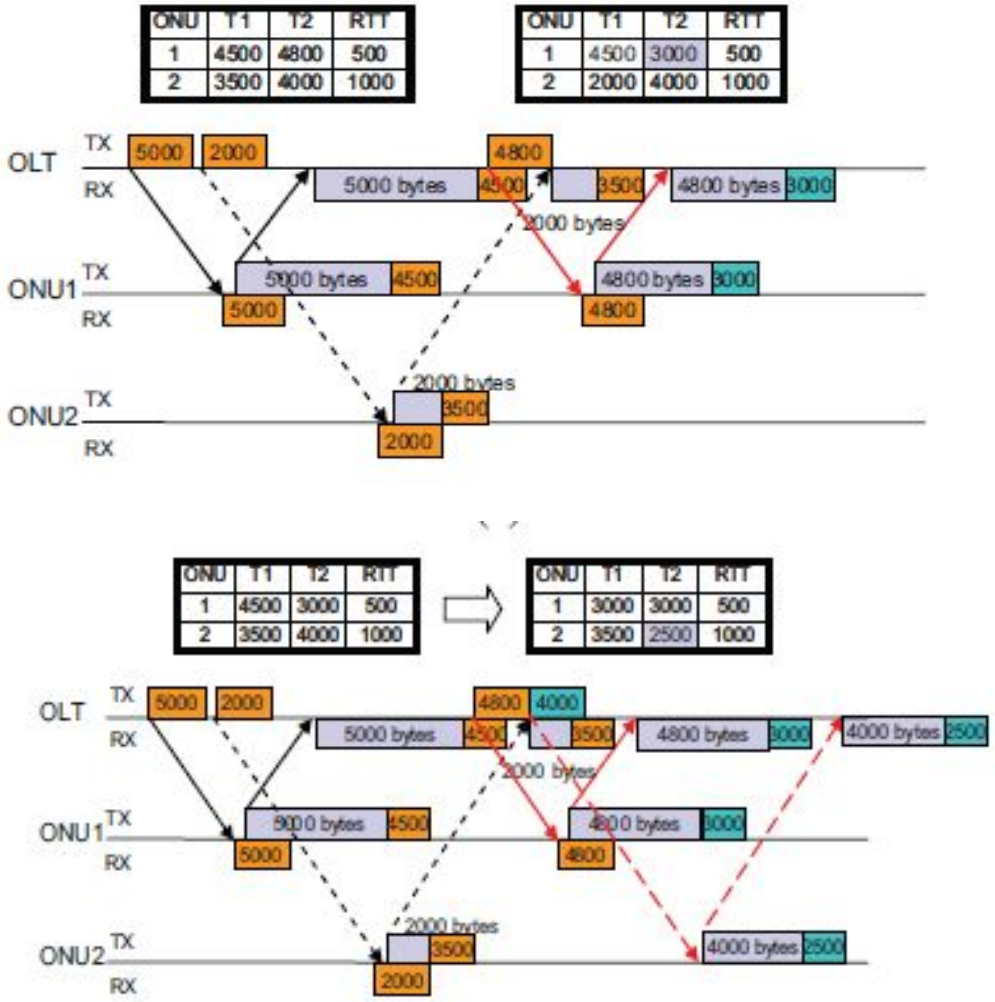


ONU	T1	T2	RTT
1	4500	4800	500
2	2000	4000	1000

ONU	T1	T2	RTT
1	4500	4800	500
2	3500	4000	1000



Multi-thread Polling- Example



Multi-thread Polling- Control Frame

- GATE (Grant) and REPORT (Request) are 64-byte medium-access control (MAC) frames. Besides the information of source, destination, timestamp
- MPCP reserves 44-byte “opcode-specific fields” for specific MPCP functions

- Multi-thread polling scheme uses the reserved 44 bytes:
- REPORT:
  - Requested window size 2-byte
  - Thread number: 1-byte
- Gate:
  - Granted window size: 2-byte
  - Grant start time: 2-byte
  - Thread number: 1-byte

Multi-thread Polling-Initiating

- When OLT initiates multiple threads, the initial cycle time of each thread is set to value *t*. The relation of *t* and the total number of threads *N* is:

$$N = \left\lceil \frac{Max\,(RTT) + T_{process}}{t} \right\rceil$$

- *Tprocess* is the Request processing time at the OLT

Multi-thread Polling-Inter-Thread Scheduling

- In multi-thread polling, OLT can make use of not only the information of Requests in the current thread, but also the one in subsequent threads before the time the OLT calculates bandwidth allocation
  - For example, consider that three threads T1, T2, and T3. Before OLT calculates bandwidth allocation in T1, Requests in T2 have arrived, which report the latest information of ONUs' packet queues
  - This information will be counted in the bandwidth allocation in T1. Thus, packets arriving at ONUs in T2 will not be queued until Gates of T2 are received; instead, they can be transmitted in T1. So, the average packet delay can be further optimized

Summary

- MCMP
  - Auto discovery, DBA
- APON, BPON, GPON
  - All transmits ATM cells
- EPON
  - Transmits Ethernet frames
- DBA in EPON
  - Offline vs. Online, polling mechanisms, channel idle time problem , Early allocation and Grant estimation
- QOS in EPON
  - Priority Queues, minimum bandwidth window, GBR vs. GAR
- LR-PON
  - Super PON extends operational range up to 100Km
  - Thread & Multi Threading