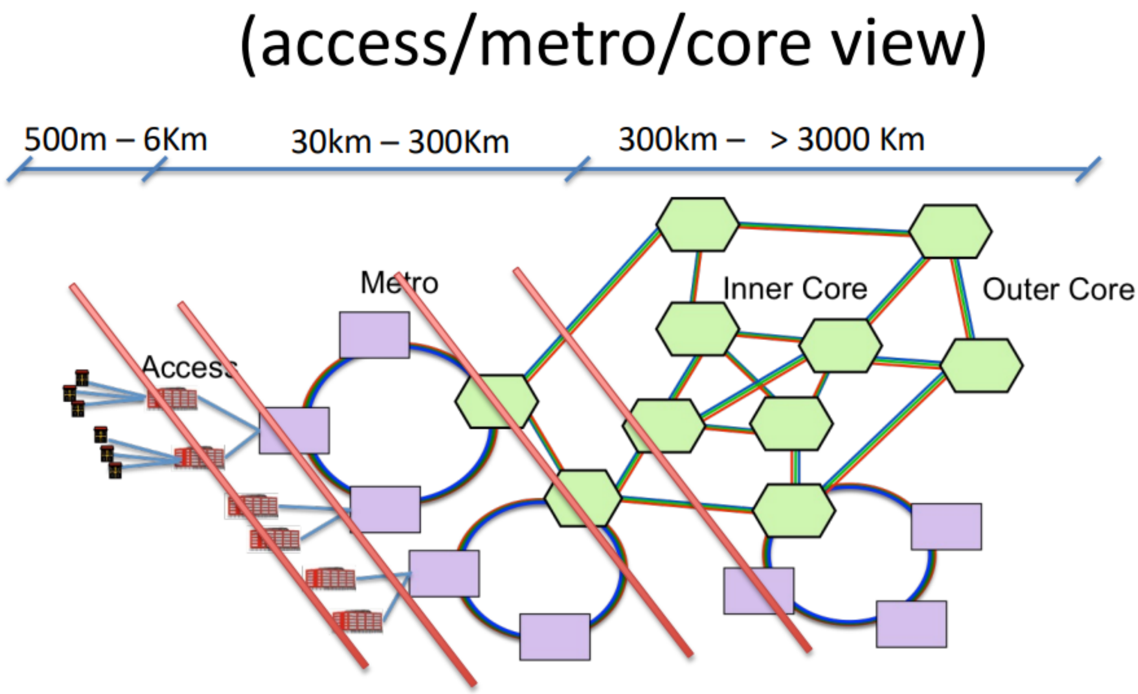
Fixed access networks

Terms

- OEO = Optical-Electronic-Optical
- CPE = Customer Premise Equipment
- CO = Central Office
- ADSL = Asymmetric Digital Subscriber Line
- DMT = Discrete Multi-Tone Modulation
- OFDM = Orthogonal Frequency Division Multiplexing
- FTTC = Fibre-to-the-cabinet
- VDSL = Very-high-bitrate DSL
- TDD = Time Division Duplexing
- FTTDp = Fibre-to-the-distribution-point
- DP = Distribution point
- FTTB = Fibre-to-the-building
- FDX = Full-Duplex Transmission
- PON = Passive Optical Network
- FTTP = Fibre-to-the-premises
- GE = Gigabit Ethernet
- OLT = Optical Line Terminal
- ONUs = Optical Network Units
- TDMA = Time Division Multiple Address
- Sonet = Synchronous Optical Networking
- SDH = Synchronous Digital Hierarchy
- GTC = GPON Transmission Convergence
- GEM = GPON Encapsulation Method
- CRC = Cyclic Redundancy Code
- DBA = Dynamic Bandwidth Assignment
- RTD = Round-Trip Delay
- T-CONT = Transmission Container
- EPON = Ethernet Passive Optical Network
- IPACT = Interleaved Polling with Adaptive Cycle Time

Network architecture



Cost vs. aggregation

	Access	Metro	Core
Aggregation factor	As low as 1:1 for CPE, 1:10K for CO	1:100K to 1:10M	1:1M to 1:100M+
Capacity	1 Mb/s to 1 Gb/s	10Gb/s to 100s Gb/s	100Gb/s to 10s Tb/s
Volume of expected sold units	Very high (even more than one per user)	Medium	Low (relatively few links)
Cost per unit	Must be very low	Medium	Can be high

Statistical multiplexing

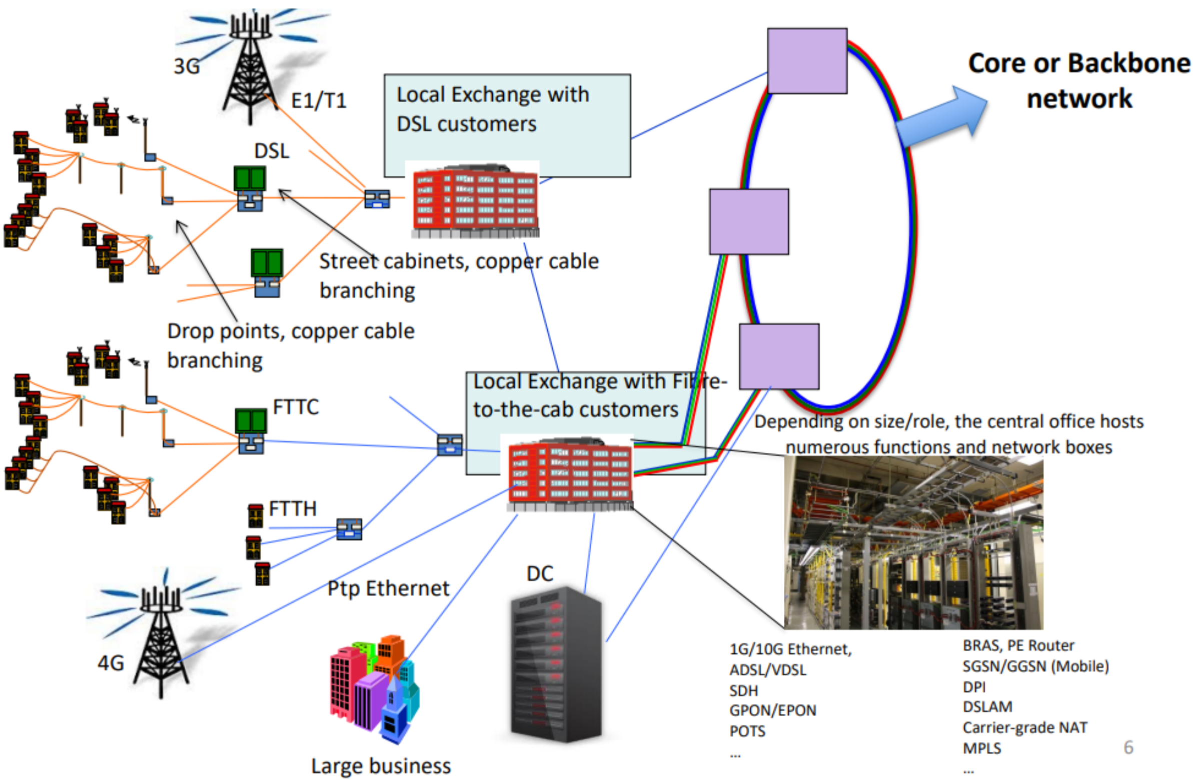
$$P(k\ successes\ in\ n\ trials) = \binom{n}{k} p^k q^{n-k}$$

$$\text{with } \binom{n}{k} = \frac{n!}{k!(n-k)!}$$

- k= No users for which probability is assessed (1,100)
- n= No of total users (100,000)
- p= probability of user in network (1%)
- q=1-p

We want the cumulative probability P (X >1,100) users are in the network: $\sum_{k=1,100}^{100K} P$

Access and metro network view



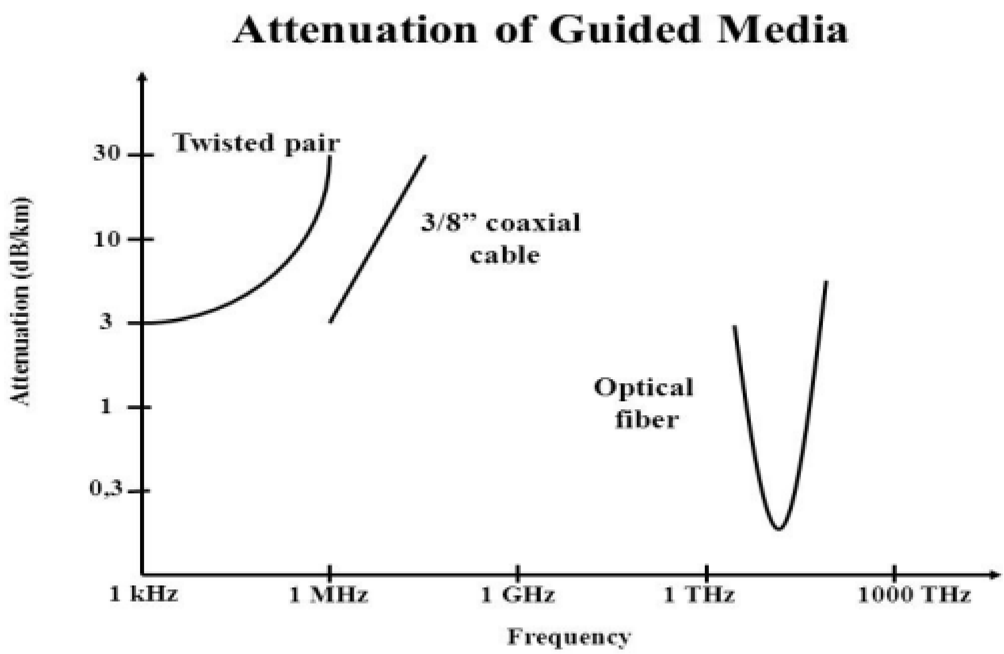
Access network speed

- Fastest access speed to the user 1-10Gb/s
- Fastest core network link over 40Tb/s (over one fibre)

Issues with access networks

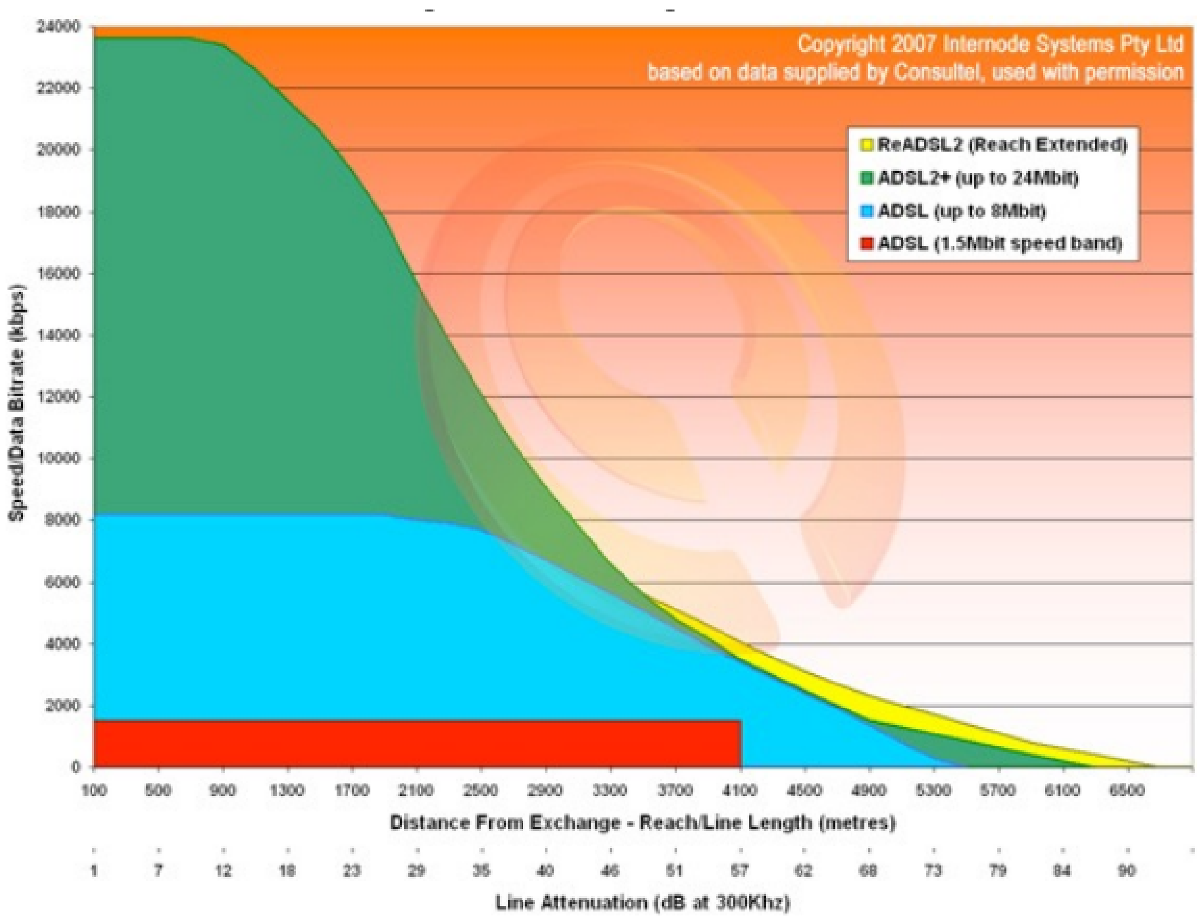
- cost per connection upgrade, on a per-user basis

Twisted pair and coaxial



- Twisting the copper helps reducing interference from external sources
- coaxial uses the Faraday principle by using an external sheet to confine the radiation

Capacity vs. distance of DSL



Shannon–Hartley theorem

$$C = B \cdot log_2\left(1 + \frac{S}{N}\right)$$

C = capacity [b/s]
B = bandwidth [Hz]
S/N = Signal to noise ratio [linear]

The solution is to reduce the distance of the copper link

DSL details

- ADSL: 1.1 MHz bandwidth, Discrete Multi-Tone Modulation (DMT), 256 channels, 8 Mb/s DS, 1.3 Mb/s US
- ADSL-2: 1.1 MHz bandwidth, DMT but improving modulation efficiency, reducing framing overhead reducing framing overhead, 12 Mb/s DS, 3.5 Mb/s US
- ADSL-2+: 2.2 MHz bandwidth, using DMT, 24 Mb/s DS, 3.3 Mb/s US

Fibre-to-the-cabinet

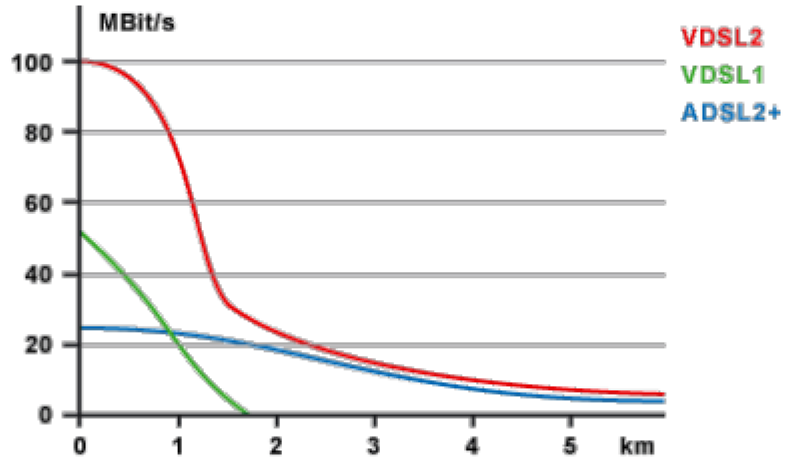
- Replace the first part of the copper (that shared by most users) with fibre
- DSL works on the fast side
- higher SNR allows to develop also better technology

FTTC technology

Main feature: twisted copper pair is used in some part of the connection.

VDSL/VDSL2

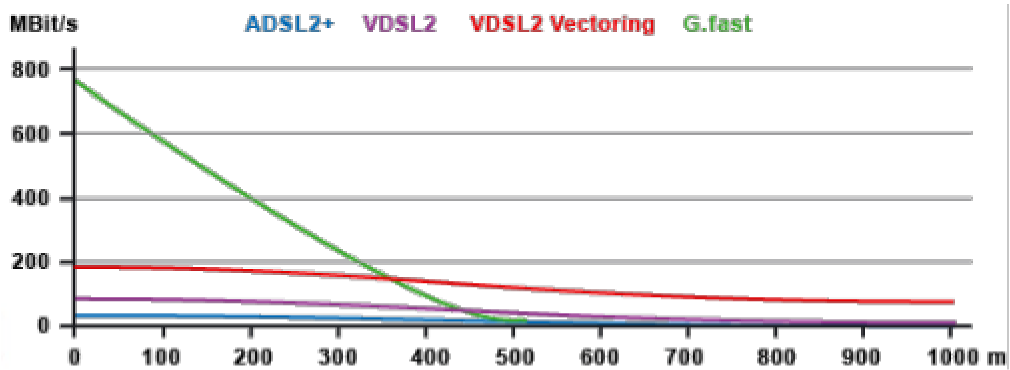
- VDSL: 52 and 16 Mbps, DS/US, frequencies 12 MHz
- VDSL2: frequencies 30 MHz, symmetric 100MB/s capacity



Vectoring

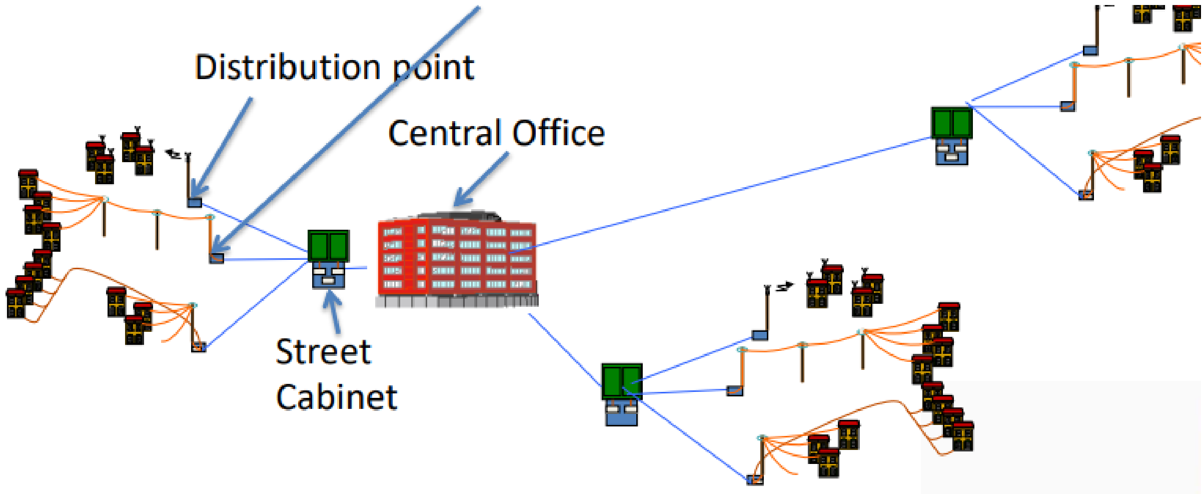
- applies noise cancellation to the line, but needs to access all interfering lines

G.FAST



- increases the rate by using much larger bandwidth, up to 106 MHz
- overlaps with FM radio
- due to overlap with ADSL and VDSL, the starting frequency can be set between 2 and 30 MHz
- targeting distances 500m
- TDD, so the DS/US ratio can change (e.g., 90/10 or 50/50)
- can work both for FTTC and FTTDp

Fibre-to-the-distribution-point (FTTDp)



- Replace the copper all the way to the DP
- distance decreases to about 50 -100m
- referred to Fibre-to-the-building (FTTB)

FTTDp technology

- G.FAST
- XG.FAST

XG.FAST

- 10Gb/s symmetric
- uses bandwidth up to 500MHz
- Bonding: use of two copper pairs per users
- Phantom mode: create a third virtual pair of two physical copper pairs
- Adanced cross-talk cancellation
- Full-Duplex transmission (FDX): use same bandwidth both DS and US with echo cancellation

FTTDp backhaul

- Put point-to-point fibre
- Cost saving by Passive Optical Network (PON)

Fibre-to-the-home (FTTH)

- Replace the copper all the way to the house (or premises – FTTP)

Technology

Passive Optical Networks (PON)

- Time division multiplexing
- Wavelength Division Multiplexing
- Time/Wavelength Division Multiplexing

Time Division Multiplexing PON

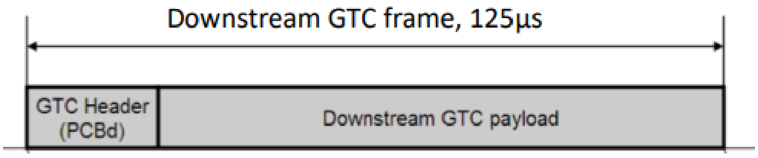
- The protocol is based on TDM/TDMA
- Downstream the OLT broadcasts data to every ONU, and each ONU filters out the data destined to it
- Upstream is different as all data will converge into the same link to the OLT (needs MAC)

Downstream frame

- Each frame is 125μs long (inherited from Sonet/SDH standards)
- The frame is scrambled
- GTC payload carries multiple GEM frames

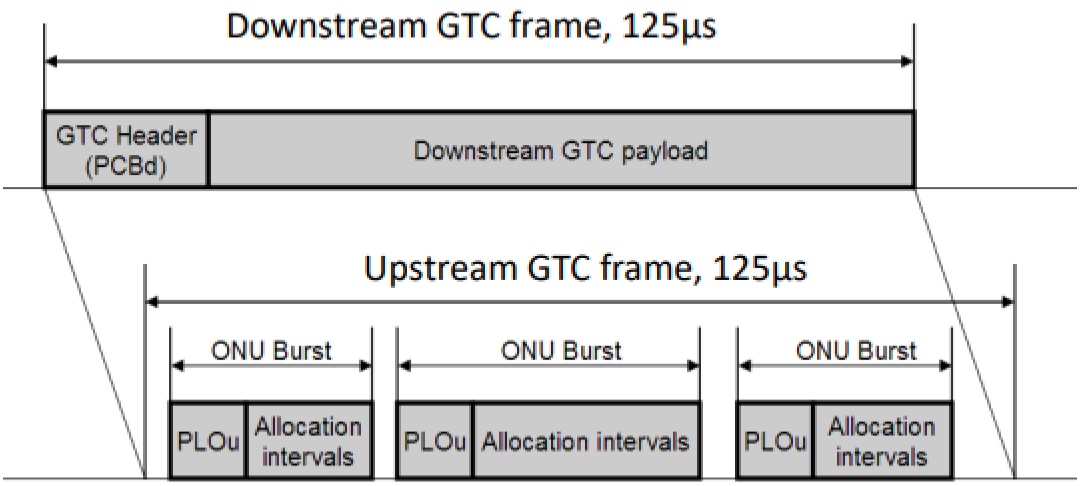
– The opposite function (de-scrambling) is applied at the receiver

– Used to avoid too many 1s or 0s in sequence (can loose synchronization)

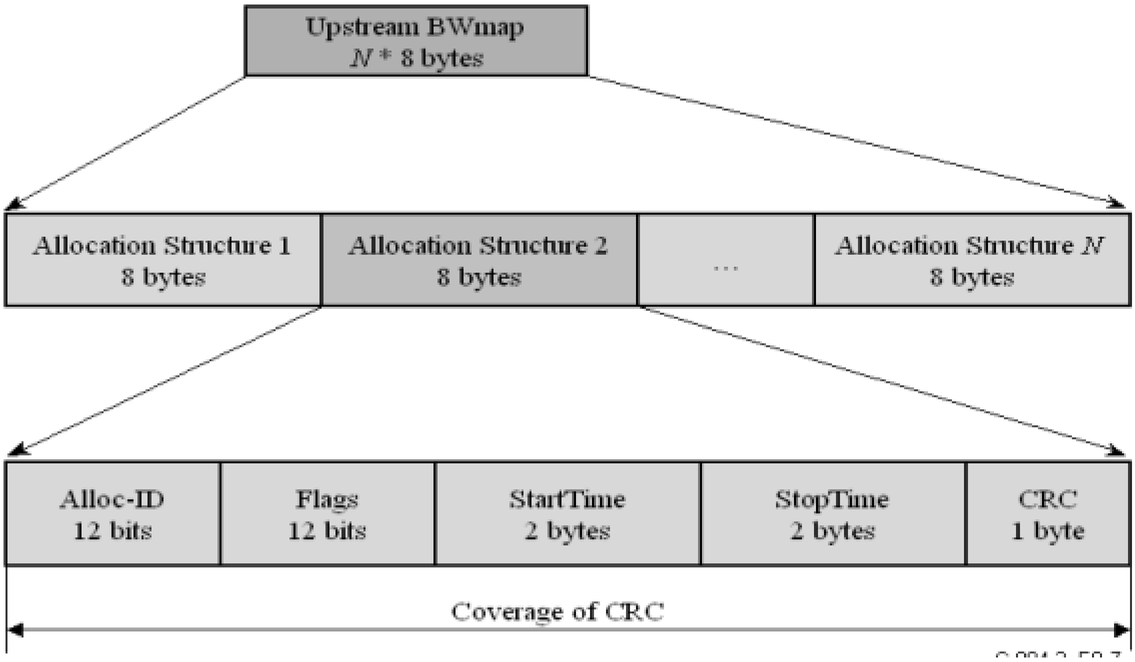


Upstream burst structure

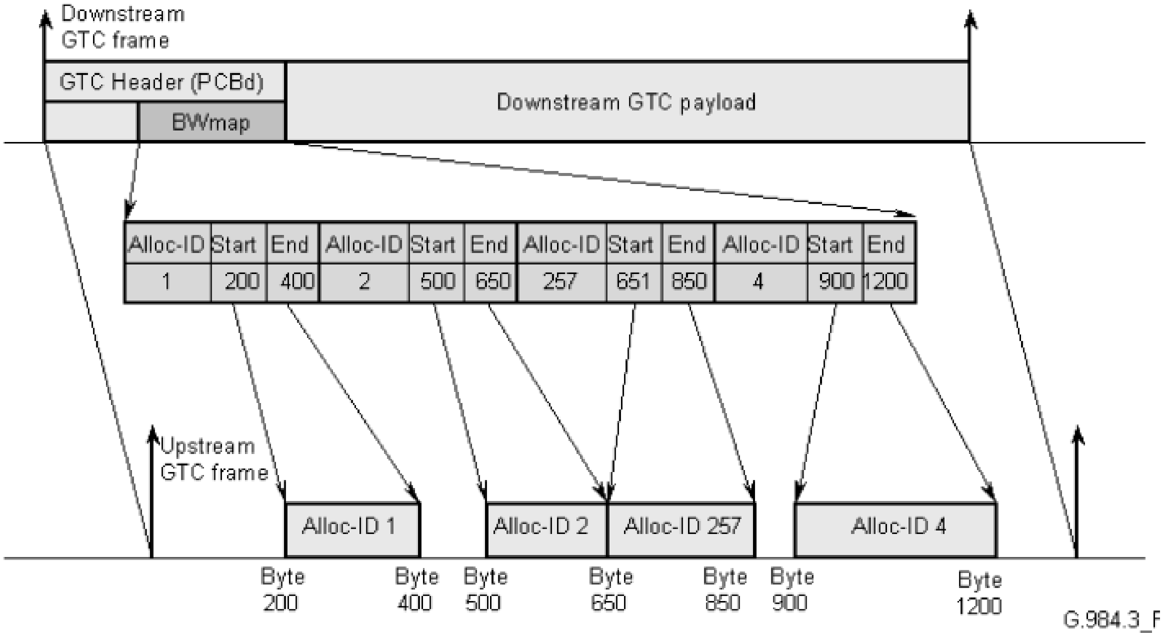
- is arranged in bursts
- a sequence of burst is delimited within a frame of 125μs
- bursts are also scrambled



Bandwidth map for upstream traffic scheduling

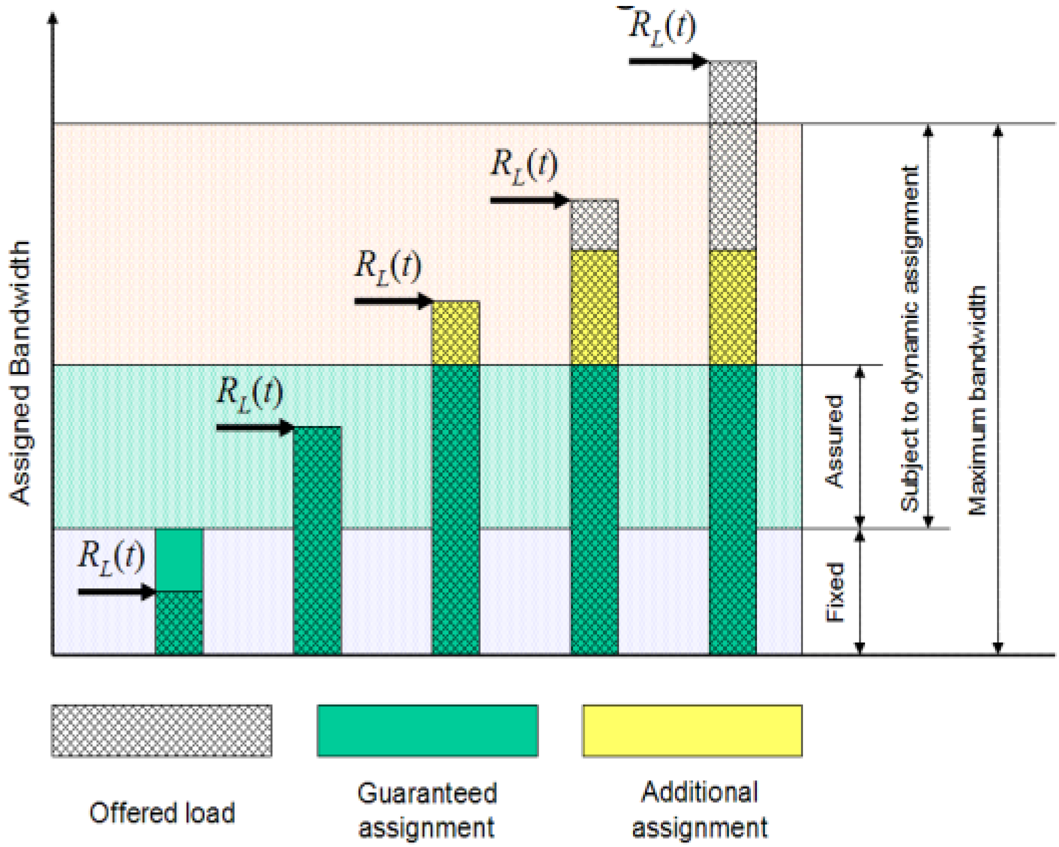


Bandwidth map



Dynamic Bandwidth Assignment (DBA)

- OLT decides how to assign upstream transmission opportunities (e.g., bandwidth) to the ONUs
- Status reporting: the ONU informs the OLT on how much bandwidth it needs
- Traffic monitoring: OLT decides based on the observed traffic pattern



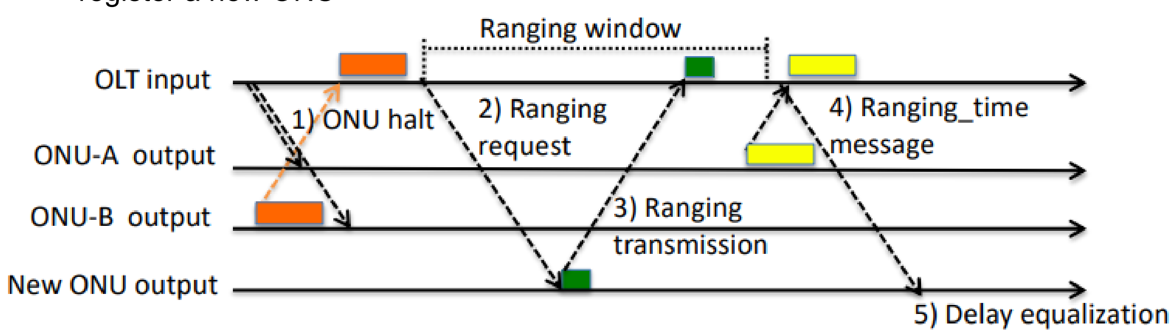
status reporting

- ONUs send their DBRu (current queue size)
- DBA calculates how much capacity each ONU should get
- It sends the bandwidth map which informs all ONUs when to transmit and how many bytes for the next upstream frame

Ranging operations

phase 1

- register a new ONU



1. The OLT sends a halt msg to all ONUs to stop upstream transmission
2. OLT request serial number to unregistered ONU(s)
3. After receiving the request, an unregistered ONU transmits the serial number after waiting for a random time (up to 48 μs)

4. The OLT registers the ONU assigning it an ONU-ID value

phase 2

1. OLT sends a halt msg to all ONUs to stop upstream transmission
2. OLT sends a Ranging request to a specific ONU (using ONU-ID)
3. The ONU with that ONU-ID sends back a Ranging message to OLT
4. OLT calculates the RTD for that ONU and notifies the ONU of its Equalization Delay(=Teqd-RTD), where Teqd is max RTD (e.g., 200μs)
5. The ONU stores the Equalization delay and uses it for all upstream transmissions

Difference between GPON and EPON upstream

GPON

- uses traffic containers (T-CONT) as uplink traffic scheduling units to enable QoS service
- Each ONU can have multiple T-CONTs with different classes

EPON

- Looser standard definition, use of “packetized” Ethernet packets frame structure

Duplex scheme

- The most (economically) convenient duplex scheme is wavelength division duplex

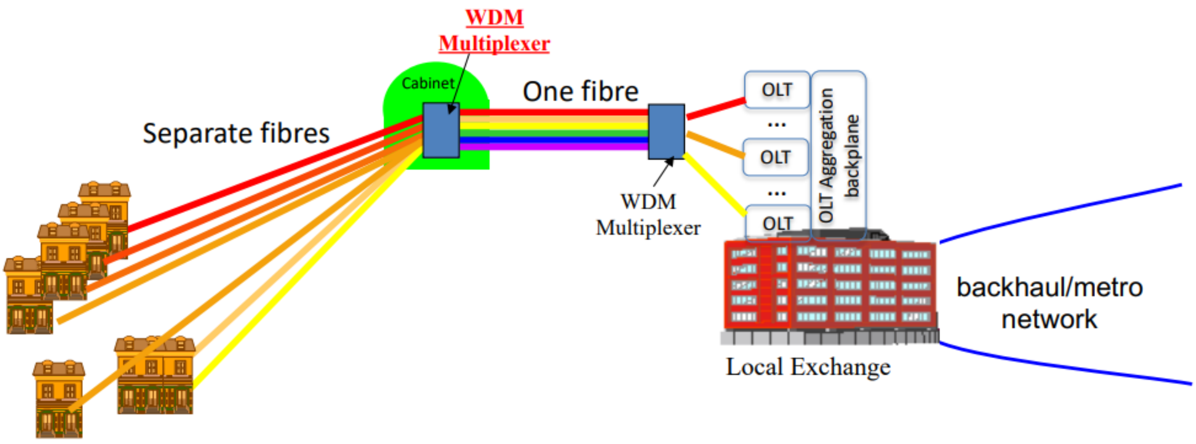
Split ratio

- the total number of ONUs that can be served by one OLT, i.e., the number of leaves of the PON tree
- Allow better cost sharing
- Lower capacity per user
- increases the optical loss, by 3 * log2(N), where N is the number of splits
- The GPON standard include split ratios from 1:16 up to 1:64, and max ONU-OLT distance of 20km

Security Issues

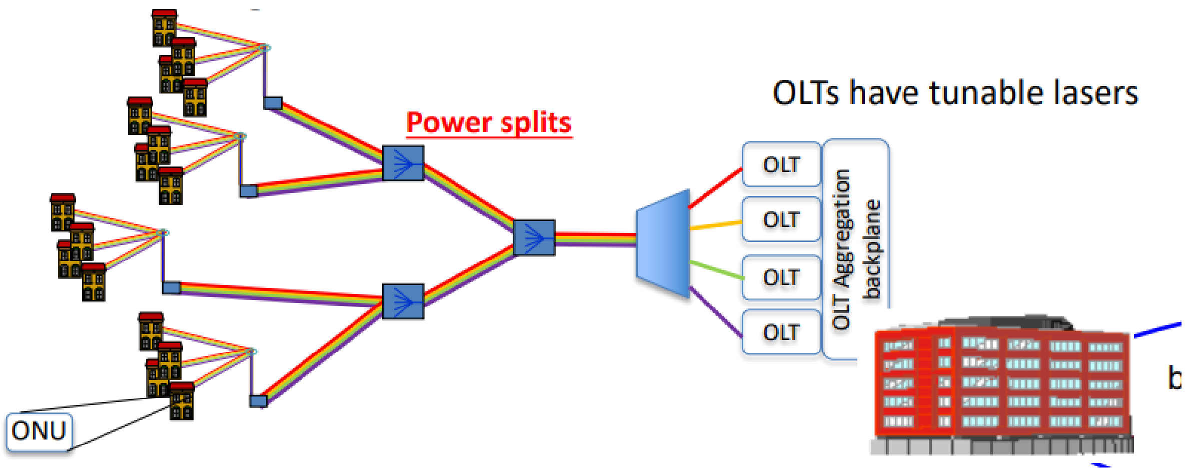
- basic security problem with GPON, and other PONs based on power splitters is that messages are physically broadcast by the ONUs and filtered by the ONUs
- The solution is to use cryptography, using an initial key that is preestablished
- Upstream this is not an issue

Wavelength Division Multiplexing PON



- each user is served by a separate wavelength channel and a WDM splitter is placed in the cabinet
- Logically it is a point-to-point connection
- The issue is that a wavelength is fixed to a destination

Time/Wavelength Division Multiplexing PON



- ONUs can tune laser and receiving filter to select a different OLT
- Passive splitters and tunable end point is the most flexible solution

Wavelength tuning issues

- Wavelength tuning is expensive

Standard

- IEEE P802.3ca task force and ITU-T working on >10G speed. This is strongly driven by low-cost optical Ethernet components.
- IEEE 25G-EPON recently standardized (two wavelengths for 50G, 1342 and 1358 nm)
- ITU-T 25G-PON standardized, 50G in the working

Access network sharing

Copper access

- Local Loop Unbundling (LLU)
- Sub Loop Unbundling (SLU)
- Bitstream
- Virtual Unbundling Line Access (VULA)
- Bitstream Next Generation Access (NGA)
- COS = Class of Service

Fibre access

Quality of service in packet networks

Terms

- QoS = Quality of Service
- PCP = Priority Code Point
- DSCP = Differentiated Services Code Point
- TC = Traffic Class
- SLA = Service Level Agreement
- CIR = Committed Information Rate
- PIR = Peak Information Rate
- RED = Random Early Discard
- WRED = Weighted Random Early Discard

No guarantee

- Packet loss
- Latency: cannot be solved above layer 4, but needs to be tackled at layer 3 and below
- Jitter: can be solved at application level through buffers, but these increase latency
- Capacity: capacity is a layer 1 issue, although in a network it’s limited by the slowest link, so also layers 2 and 3 play an important role

QoS = prioritization

- Ethernet Priority code point (PCP) in the VLAN tag
- IP Differentiated Services Code Point (DSCP)
- MPLS Traffic Class (TC)

QoS tool

- Policer: discards packets when they go above a pre-established threshold

- Shaper: delay packets so that the bandwidth threshold is not exceeded at any given time
- Classifier: inspects an incoming packet and assigns to it a class of service (COS)
- Metering and coloring: check the rate at which packets are coming in against pre-defined thresholds and subsequently marks packets with different “colors”
- Queuing differentiation: queues all work in FIFO mode, but packets with different COS can be assigned different queues
- Scheduler: it decides in which order to get packets from the different queues
- Rewrite: it can modify a packet COS marking

Two rate Three Colour Marking

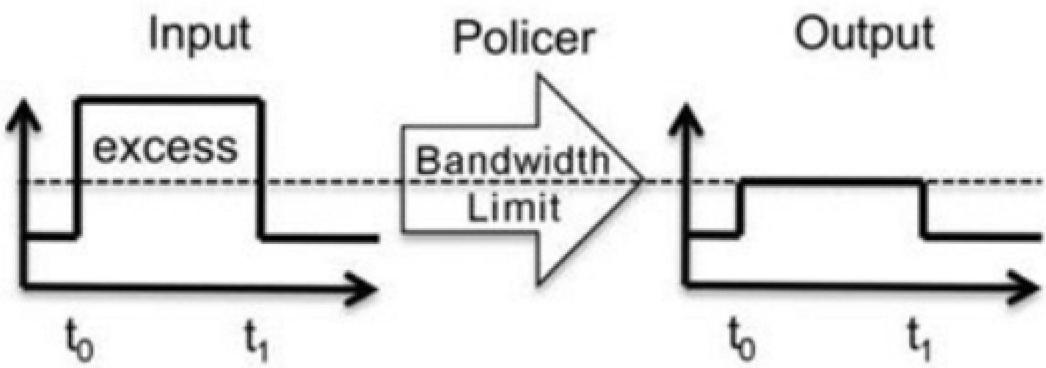
Color blind

1. Data below CIR marked green
2. Above CIR, but below PIR as yellow
3. Above PIR as red (dropped)

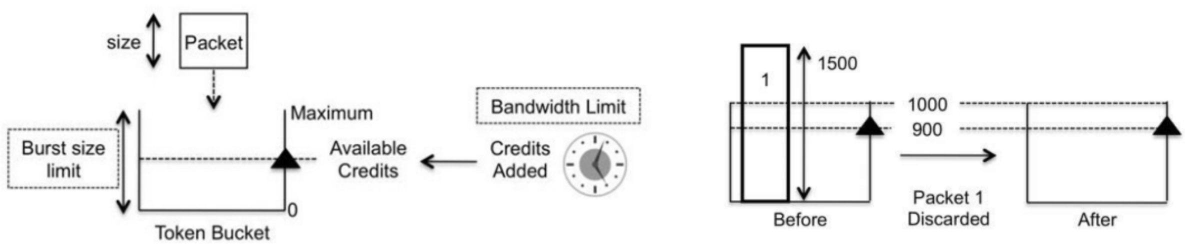
Color aware

1. Green goes into CIR queue, but if above CIR is sent to PIR queue
2. Yellow goes into PIR queue
3. Any traffic above PIR is red (dropped)
4. Notice that yellow never becomes green even if CIR still available

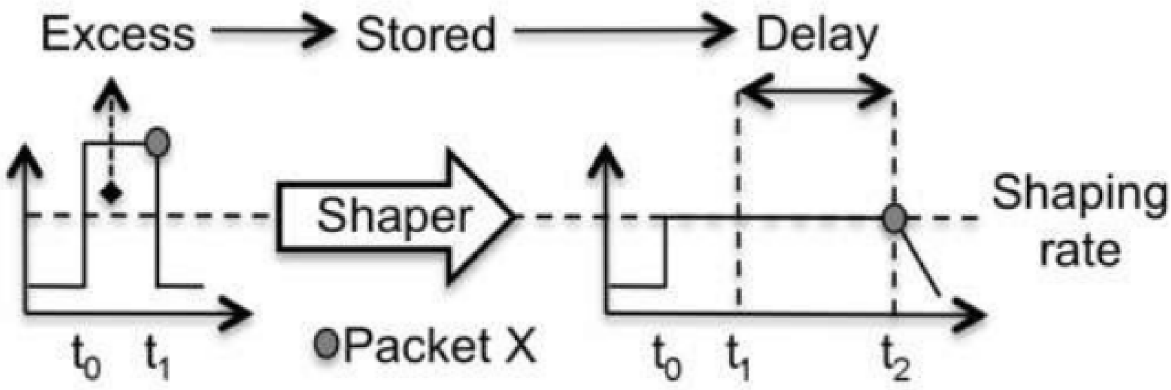
Policer



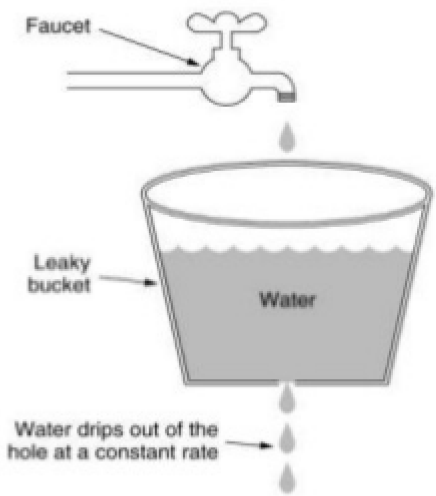
token bucket

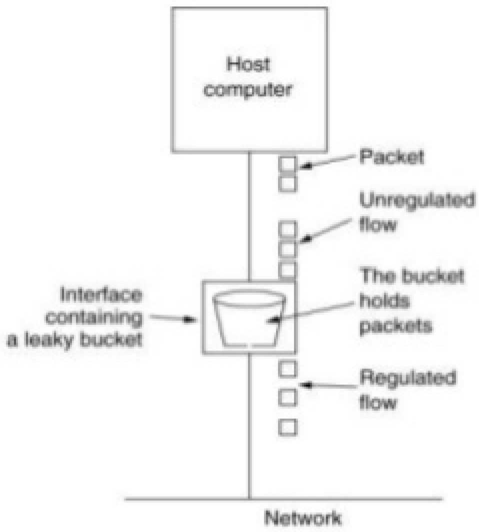


Shaper



leaky bucket

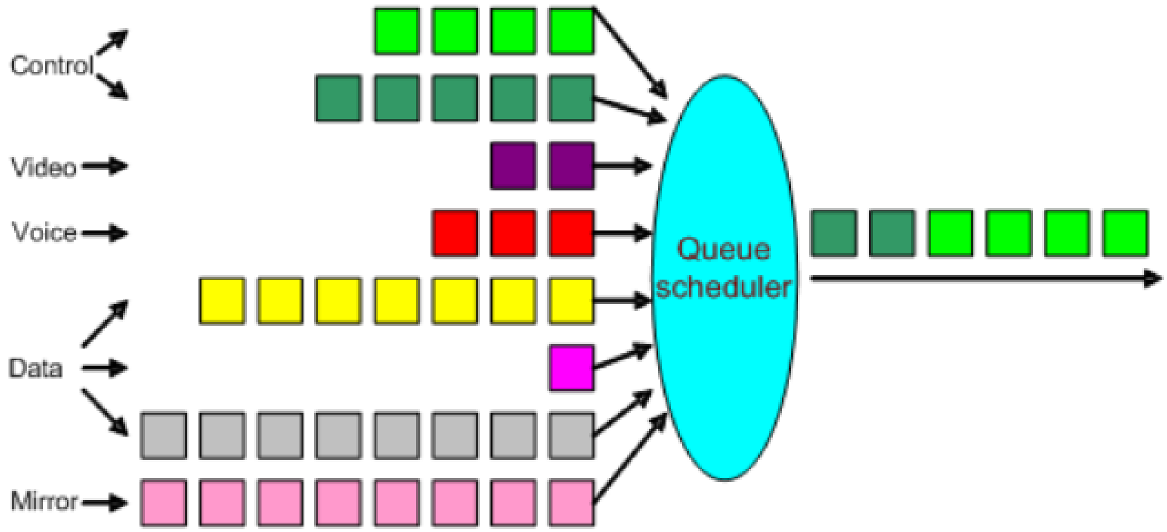




Queuing

- 8 different queues per port (Ethernet PCP, MPLS TC have 3 bits

Scheduler



Effects of QoS tools

- Packet loss caused by: Traffic policer, drop by the queue
- Latency cause by: Shaper, scheduler
- Jitter cause by: – Shaper, scheduler

Effect of queue size

- Queue size affect packet loss, delay and jitter
- Lower chance of queue filling up and traffic being dropped
- However packets spend longer in the queue and thus the delay increases (and so the jitter)

Schedulers implementation

FIFO queuing

- no service differentiation

Fair queuing (FQ)

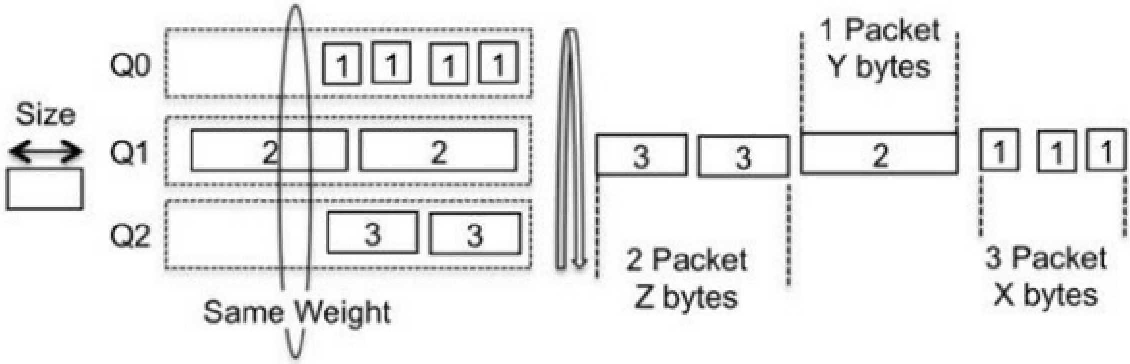
- does not provide QoS differentiation because it's fair to all flows

Strict Priority queuing (SP)

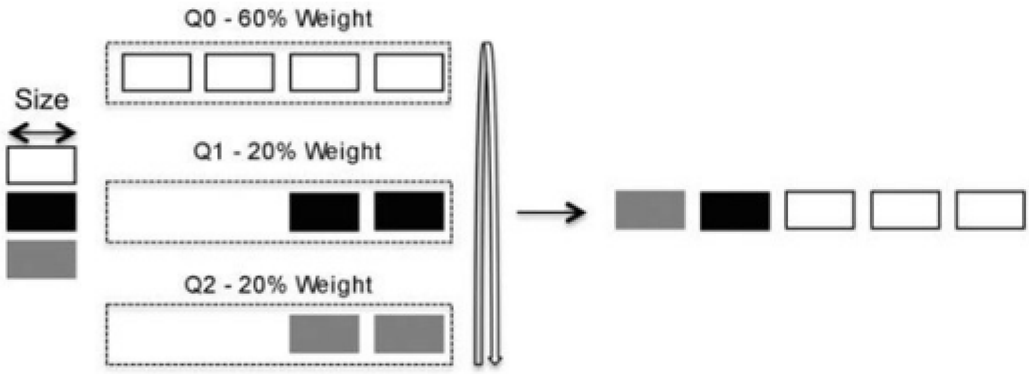
- strict as Q1 is not served until Q0 is empty
- Low priority traffic can become stalled

Weighted fair queuing (WFQ)

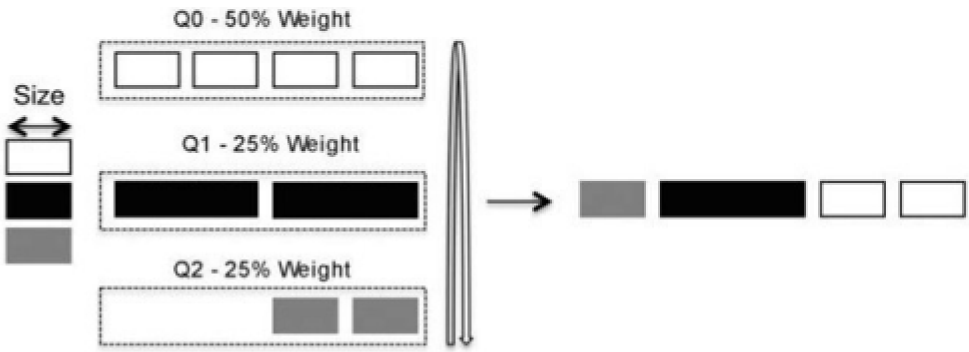
- a queue with smaller packets will transmit more



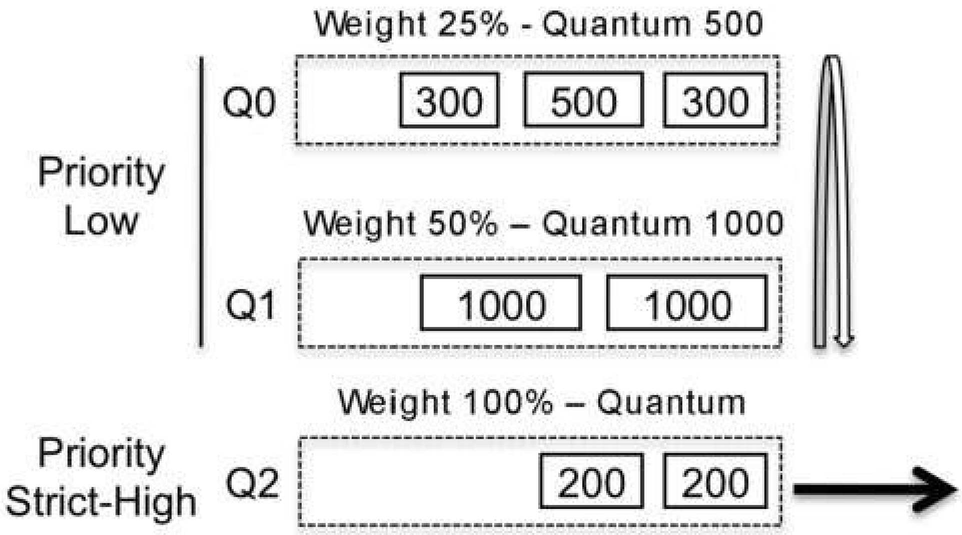
Weighted round robin (WRR)

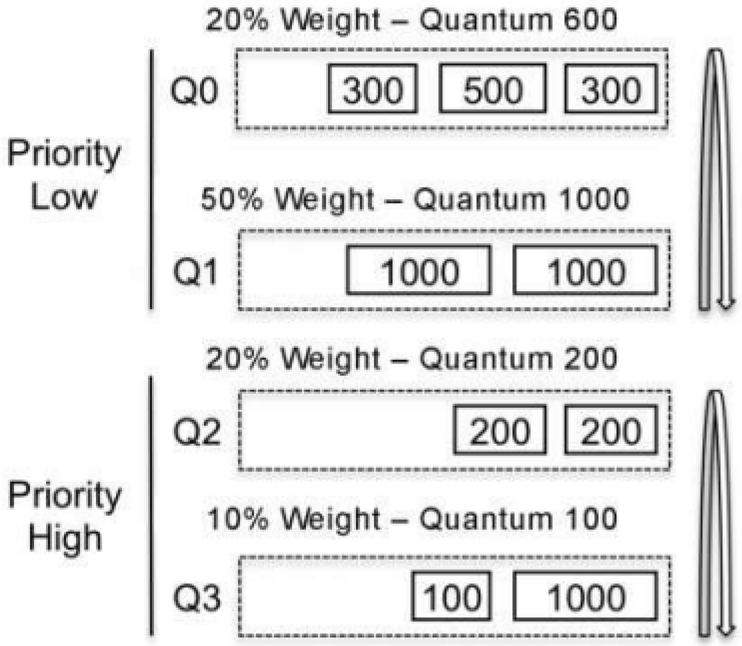


Deficit weight round robin (DWRR)

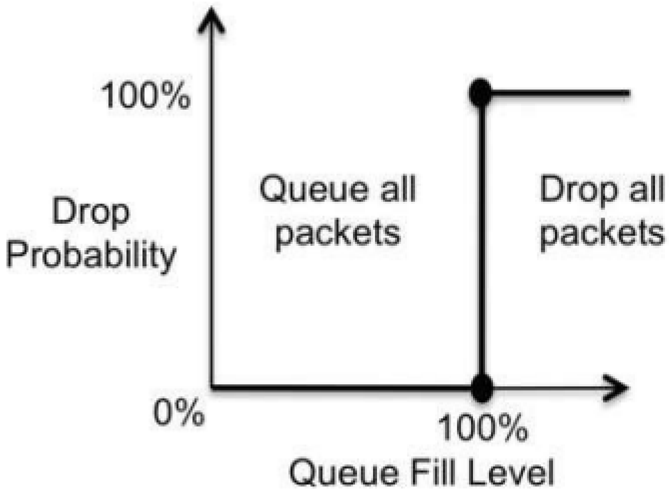


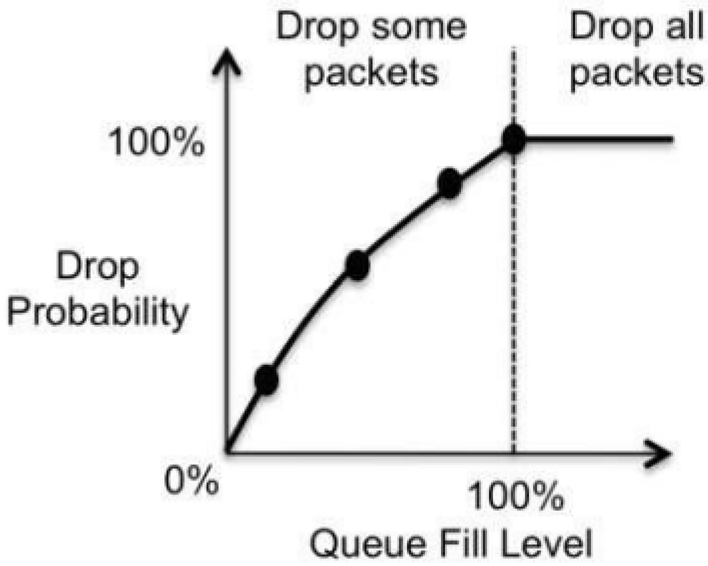
Priority-based deficit weighted round robin (PB-DWRR)



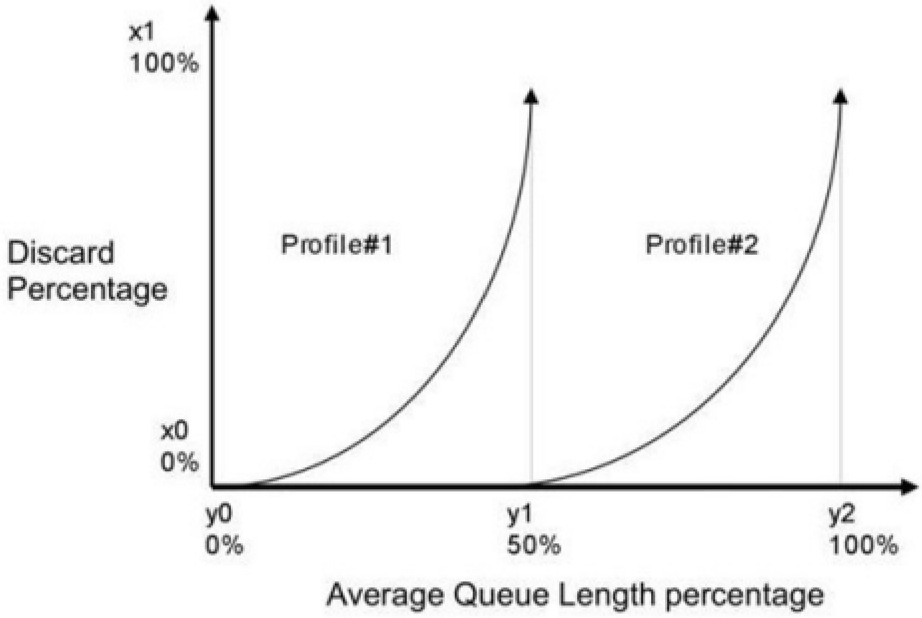

20% Weight – Quantum 600
Q0
300
500
300
Priority
Low
50% Weight – Quantum 1000
Q1
1000
1000
20% Weight – Quantum 200
Q2
200
200
Priority
High
10% Weight – Quantum 100
Q3
100
1000

RED


100%
Drop
Probability
Queue all
packets
Drop all
packets
0%
100%
Queue Fill Level

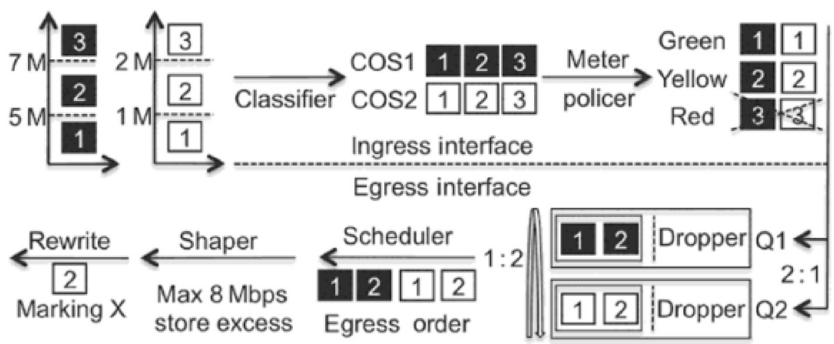

Drop some
packets
Drop all
packets
100%
Drop
Probability
0%
100%
Queue Fill Level

WRED



Example

Traffic	Class of service	Metering and policing			Queue	Scheduler	Egress rate	Rewrite
		Rate	Color	Action				
Black	COS1	<5 M	Green	Accept	Use Q1	Prioritize Q1	Limit 8 Mbps store excess	None
		>5 M<7 M	Yellow	Accept				
		>7 M	Red	Drop				
White	COS2	<1 M	Green	Accept	Use Q2			
		>1 M<2 M	Yellow	Accept				Marking = X
		>2 M	Red	Drop				None



Fixed mobile convergence

Terms

- RAN = Radio Access Network
- BBU = BaseBand Unit
- CPRI = Common Public Radio Interface
- RRU = Remote Radio Unit
- NFV = Network Function Virtualization
- RAT = Radio Access Technology
- HARQ = Hybrid Automatic Repeat reQuest
- RAN = Radio Access Network

popular estimates of factors for capacity increase

- Efficiency (MIMO, Smart scheduling, enhanced-CoMP) -> x3
- Spectrum (Carrier Aggregation, New Bands, Authorized Shared Access) -> x2
- Density (Advanced Macros, HetNet management, Flexible small cells) -> 167

Cell density issue

- Backhauling a macro BS with fibre, is feasible from a cost perspective
- each (small) cell only serves a few users at a time, the revenue of that small cell is much less than that of a macro cell

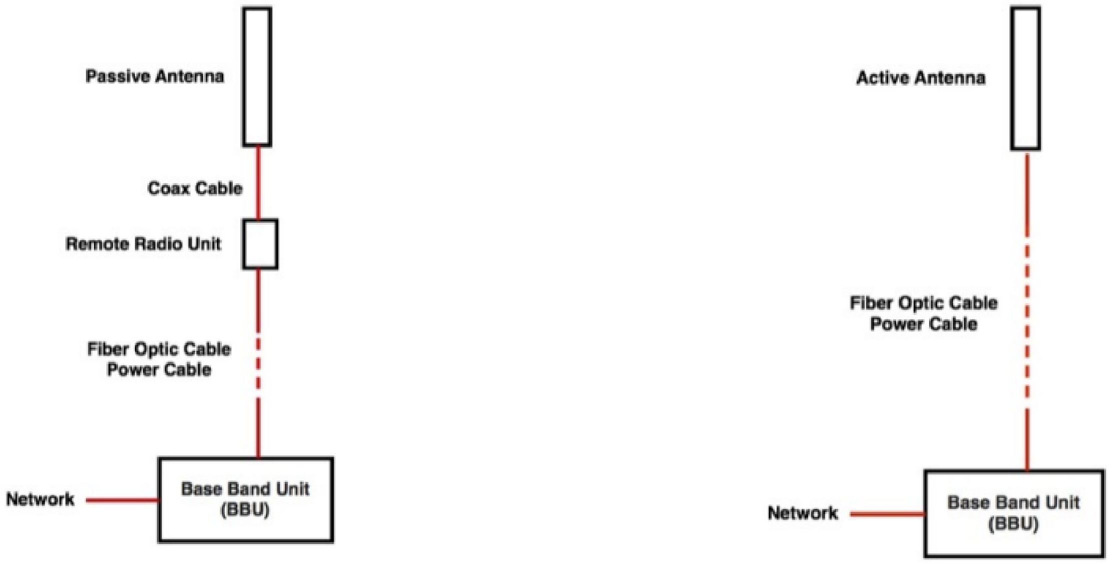
distributed RAN

Coax

generating problems of bulkiness, wind resistance and ultimately cost

Fibre optics

One single fibre has enough capacity to replace all copper wires and takes up a very small space



CPRI

all digital processing is done at the BBU, and then the RF signal is sampled, digitized and sent to the RRU over fibre.

BBU Hoteling

Once you define a fibre interface between BBU and RRU, you get in principle the advantages of fibre transmission, why not placing the BBU in a completely different location, use the same building to place more than one BBU, each connected through fibre to its own antenna mast

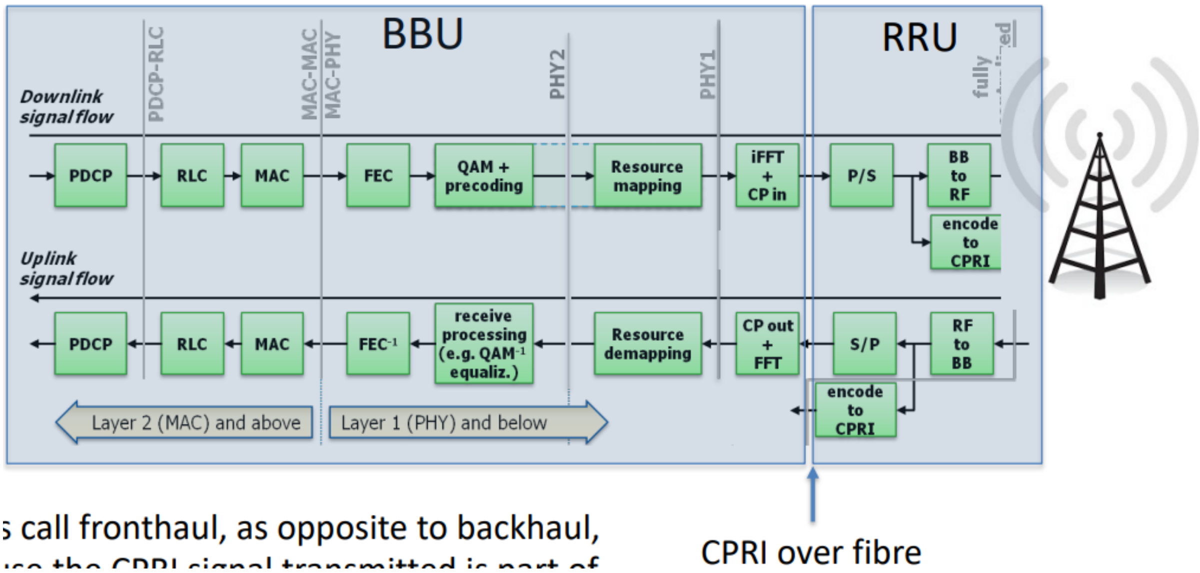
BBU pooling

trying some statistical multiplexing of the data and use a smaller number of BBUs, BBU becomes a software instance running on top of a server

Cloud-RAN

don’t need to place your servers in a number of locations, but you can build a large data centre

Fronthaul



Fronthaul transmission rate

$$R = R_s \times N_q \times N_a \times N_b \times R_c \times R_l$$

- R_s is the sampling rate, and is 30.37MHz for a 10MHz wireless bandwidth (notice that there is oversampling)
- N_q is the number of bits used to digitize each samples and it's typically 15 bits
- N_a is the number of antennas used
- N_b is the number of 10MHz frequency bands used
- R_c is the overhead given by word control ratio (16/15)
- R_l is the overhead given by he line coding (10/8 or 66/64)

Fronthaul requires a transmission capacity 16 times higher than the equivalent backhaul rate!

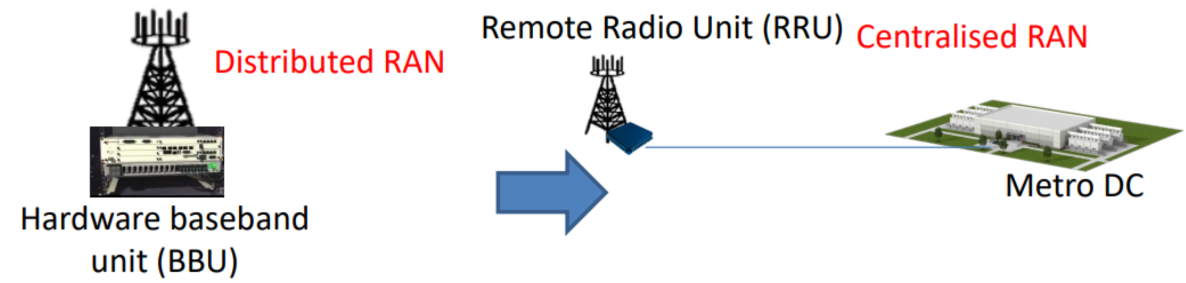
Fronthaul latency issue

typically the fronthaul transmission part over firbe is given a constraint of 200-400 us è 20-40km RTT in fibre (only transmission)

Solution for Fronthaul capacity issue

Split PHY processing or midhauling

- Doing a bit more processing at the RRU can reduce the optical transmission rate considerably
- In addition it restores the proportionality with the user traffic, thus reintroducing the possibility of carrying out statistical multiplexing



fixed/mobile convergence: variable rate fronthaul

- BBU -> SDN: Assess capacity used by the cell
- SDN -> BBU: Adaptation of wireless bandwidth
- SDN -> PON: Adaptation of reserved PON capacity to new fronthaul rate

DBA latency issue (only in upstream)