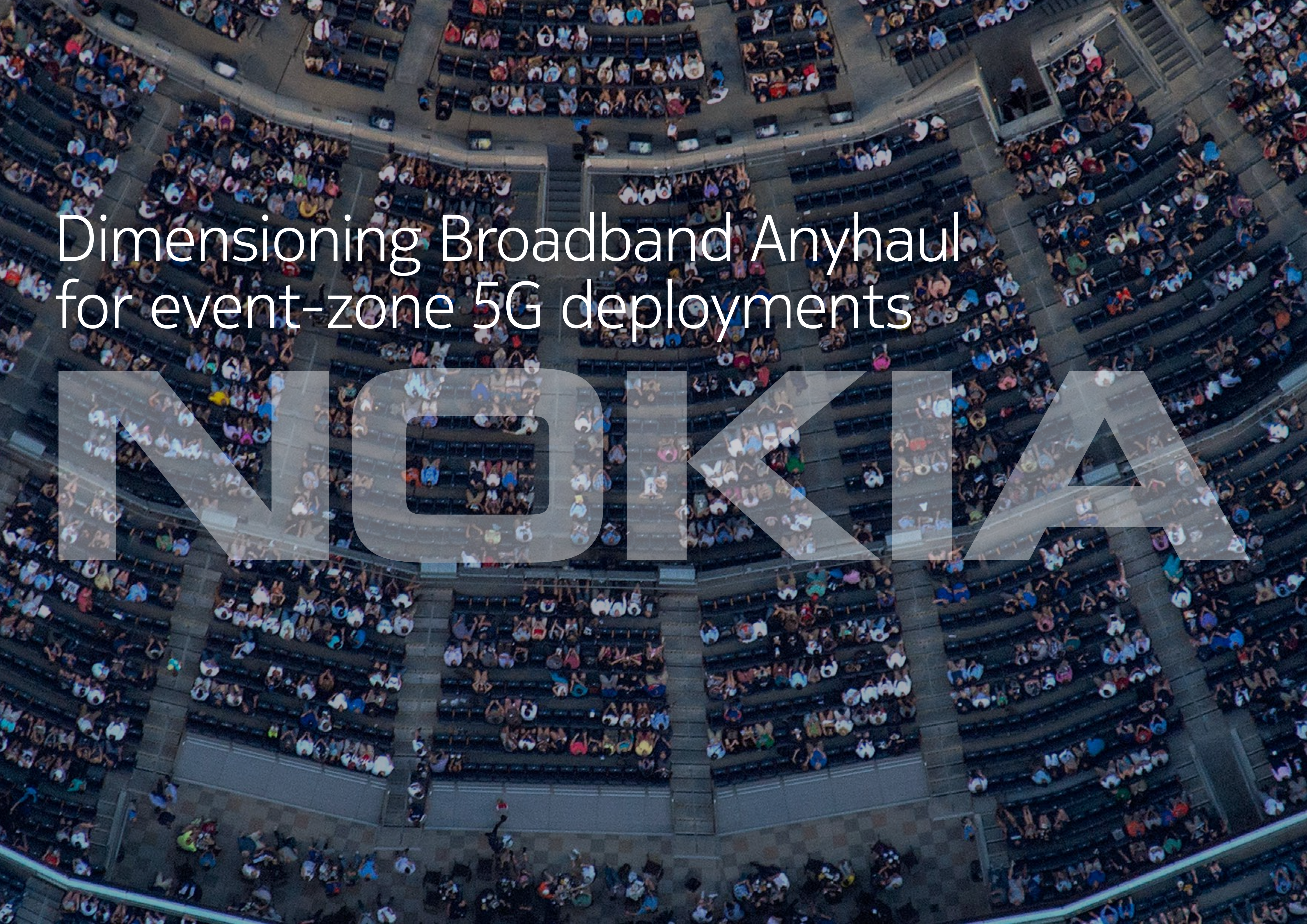
Dimensioning Broadband Anyhaul for event-zone 5G deployments



5G Enhanced Mobile Broadband (eMBB) is considered one of the first use cases for 5G deployments, bringing a better end-user experience with increased capacity, anywhere connectivity and enhanced mobility.

In this case study created by Nokia for a Tier-1 European mobile operator, we demonstrate how a service provider can leverage their fiber PON network to deliver Broadband Anyhaul for 5G eMBB services in and around a sports stadium, meeting strict parameters for throughput, latency and synchronization.

Use case overview

In the past decade, as operators have been building fiber-to-the-home networks (FTTH), they have also been laying the foundation for new opportunities in 5G. Today, these FTTH networks enable synergies between fixed and mobile networks. Delivering flawless 5G mobile services starts with a transport network that can support massive connectivity, high bitrates and low latency. To attain these targets, transport networks should be based on a variety of technologies and methods, depending on application scenarios, geographic areas and deployment models. Broadband Anyhaul using FTTH networks delivers these transport requirements in a cost-efficient way.

Nokia created this case study for a Tier-1 operator in northern Europe with a large installed FTTH network based on passive optical network (PON) technology. The study looks at dimensioning Broadband Anyhaul over PON in a scenario with a mix of early 5G Enhanced Mobile Broadband (eMBB) services.

eMBB is considered an evolution of LTE that will provide higher speeds and a better user experience. To fulfil these goals, eMBB focuses on

1. Increased capacity,
2. Anywhere connectivity, and
3. Enhanced mobility.

However, not all eMBB services will need all three requirements. Some services will need higher capacity but not necessarily enhanced mobility; for example, in sport stadiums or offices. Train passengers' needs will be the opposite.

For this case study, we have considered the following sub-cases of eMBB:

- Hot-spot overlay in a sports stadium in the middle of an urban area.
- Increased coverage and capacity in an urban area around the stadium (1/2 km^2).

The following considerations are used:

- **Radio equipment.** The scenario includes both outdoor, mast-mounted antennae components and an indoor, temperature-controlled environment (basement or foot of a mast). Indoor locations contain baseband processing units of radio access network (RAN) and PON optical network termination units (ONTs). In this example, we have used 54 radio units (RU) within the stadium premises and six RUs outside the stadium.
- **Spectrum.** For urban coverage outside of the stadium, we have selected 3.5 GHz "midband" spectrum (as sub-6 GHz 5G) which has the potential to become the most globally licensed spectrum ever for mobile communication. Within the stadium it is possible to consider mmWave at various frequencies (e.g. 26 GHz, 28 GHz, 39 GHz, 73 GHz), and for this case we have chosen 28 GHz for indoor and outdoor deployments.
- **RAN architecture.** Due to different service requirements inside the stadium and in the urban surroundings, we have considered two RAN architectures.

a. In the stadium, the operator estimated 54 RUs that will be connected to nine distribution units (DUs) (the design of which is based on the Nokia AirScale solution) located in the stadium indoor technical room.

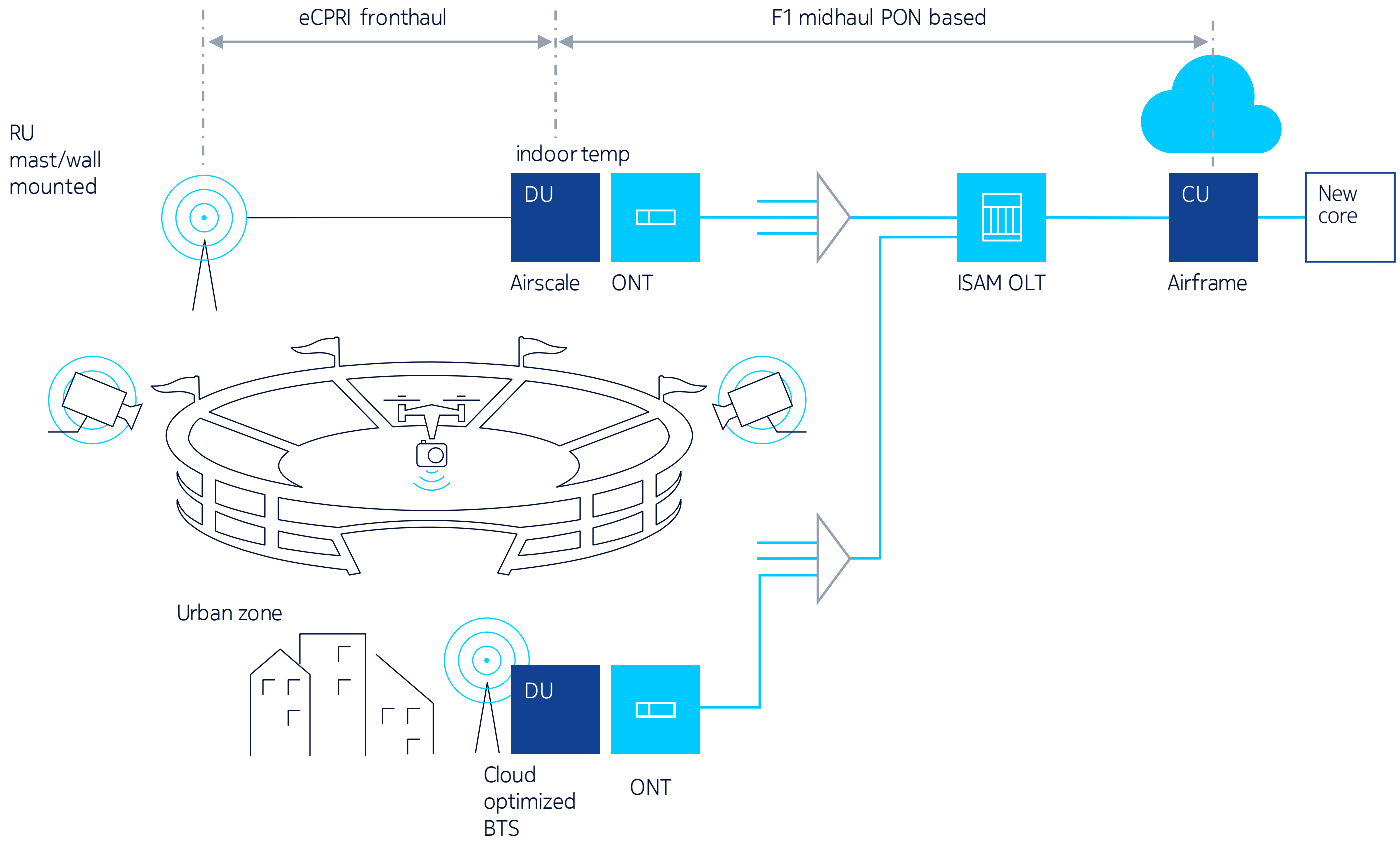


Figure 1: Proposed RAN architecture

   b. In the urban area, we have selected vRAN1.0 architecture as the most appropriate where RU and DU functionalities are collocated in six outdoor locations.
   c. In both cases, the central unit (CU) is in the edge location.
- **Edge location site.** The edge is the central indoor location for a metro area where, typically, applications and multi-access edge computing functions (MEC) are located. In urban environments there are typically only a few tens of edge locations. For our case, we assume that there is one edge location needed a few kilometers from the stadium. All applications with latency 10 ms and above are hosted in the edge data center.
- **Transport architecture.** Inside the stadium, RUs are connected to DUs with the Common Public Radio Interface (CPRI) or eCPRI fronthaul using optical transport. The midhaul connection from the stadium DUs to the CUs in the edge is PON-based. The midhaul in the urban area between the DU and CU is PON-based with an F1 interface.
- **Fiber flexibility point.** This point in the network defines where optical fiber cables will be split to reach each individual RUs. The case study assumes there is a compact central office (container-based) or a street cabinet, where the appropriate passive equipment is located.
- **PON network.** The fiber network consists of access nodes and fiber modems. Access nodes, also called optical line termination (OLT) units, aggregate the traffic from multiple connection points (residential homes, radio units) and support XGS-PON technology delivering 10 Gb/s symmetrical on each PON. Fiber modems (ONTs) are used to connect end-points. The case study is applicable for the Nokia OLT portfolio (ISAM FX/DF/SF and Lightspan FX/CF) and Nokia ISAM XGS ONTs.

To dimension Broadband Anyhaul using PON we look at the following transport network requirements:

- Throughput
- Latency
- Synchronization

Dimensioning throughput

The dimensioning of the PON network (number of access nodes, line cards, fibers, ONTs, etc.) is based on the transport throughput requirements and depends mainly on the following criteria:

- Which services will be used?
  a. Services at the stadium will be delivered for massive upload and download (videos and photos on social media), and services that enhance the visitor's experience: 360 video, AR, autonomous vehicles (drones), IoT, etc.
  b. In the high-density urban area, the target is to deliver eMBB with enhanced capacity and mobility and anywhere connectivity.
- Which 5G radio configuration is needed to deliver the desired services?
  a. For the stadium we will need mmWave radio (28 MHz), 100 MHz spectral bandwidth and mMIMO 64x64 TRX (8 layers) beaming. The outcome of this study also applies to 5G configuration with 200 MHz and 16x16 TRX (4layers).
  b. For the urban area outside the stadium the sub-6 GHz radio (3.5 MHz), 100 MHz spectral bandwidth and mMIMO 16x16TRX (4 layers) for coverage.

Dimensioning throughput inside the stadium

At the stadium, visitors typically use Wi-Fi, as it is the low-cost solution widely supported in mobile devices. If we assume 25,00 people per ½ km2 in the stadium and each Wi-Fi access point covering 10 people, the number of Wi-Fi access points is 2,500. Wi-Fi offload has been available for many years, but LTE indoor coverage needed in a stadium environment has still been a headache for operators because the integration with Wi-Fi is difficult and the user experience not seamless. Multi-connectivity and proper integration of indoor and outdoor technology is key. With multi-connectivity an important feature of 5G, this issue can now be solved.

An alternate solution for backhauling Wi-Fi access points is to use a fiber network within the stadium (also known as an Optical LAN solution). Optical LAN is increasingly used as the local area network infrastructure to deliver all services and connect all devices (PC, Wi-Fi access points, digital signage, surveillance cameras, IoT, etc.) on one network. The end-points are connected to ONUs and all traffic is aggregated on an OLT. Stadiums worldwide are already using Optical LAN, benefiting from high capacity for all their entertainment and operational services and low cost due to less cabling, lower power consumption and less space in the technical room. In this case, we assume that the average traffic per Wi-Fi access point (for 10 people) in peak hour is 20 Mb/s, allowing peaks of 1 Gb/s. This will enable flawless delivery of services in peak hours, for example at the beginning of the game when, typically, visitors upload lots of photos and videos to social media. The number of Wi-Fi access points per XGS- PON will be 8.2 Gb/s:20 Mb/s = 41, and the total number of PONs required for backhauling all Wi-Fi access points is 2500:41 = 61 PONs. Since we assumed that the OLT is already available in the technical room at the stadium, that OLT can be

# of RU	54	
# RUs per DU	6	Based on Nokia Airscale design
# of DUs	9	= 54 / 6
Peak rate per DU	4.75 Gb/s	Based on 28 MHz, 100 MHz spectral bandwidth, mMIMO 64x64
∑ avg. rates or DU	5.7 Gb/s	6 RU x 475 Gb/s x 20%
Throughput per DU		= max (4.75 Gb/s, 5.7 =Gb/s)
# of ONUs	9	Equal to #DU
+ of PONs	5	= roundup [(9 DU x 5.7 Gb/s x (1-30% stat. gain) / (8.2 Gb/s per PON)]

Table 1: Summary of midhaul calculations inside the stadium

also used to serve 61 PONs for Wi-Fi backhauling.

The radio solution used for the 54 cells in the stadium with the characteristics described above will have a peak data rate of 4.75 Gb/s.

Fronthaul

The RU-DU fronthaul connection is based on either CPRI or eCPRI over a direct fiber link.

- The CPRI link dimensioning for each RU with the above characteristics is an 80 Gb/s transport at a constant bitrate. This means a 1x100 Gb/s interface (CFP or QSFP28) is needed for each antenna (or 54 fibers inside the stadium). This is clearly not efficient due to the high cost of 100 Gb/s interfaces.
- The other possibility would be to use eCPRI instead where the transport capacity peak rate would be 15 Gb/s Ethernet, requiring 1 fiber connection to each antenna. This capacity cannot be delivered with 10 Gb/s XGS-PON so in this case we will not consider PON for fronthaul. However, future technologies, like 25G PON could fulfil this capacity need.

Midhaul

The throughput dimensioning for DU-CU midhaul is based on NGMN Alliance recommendations to calculate the average data rate in 5G as 20% of the peak rate and then consider either the maximum one-time peak or the sum of all averages, whichever is higher (Max All Average / Single Peak rule).
Each of the 54 RUs in the stadium has a 4.75 Gb/s peak. One DU typically connects six RUs, therefor the sum of all averages per DU is 6 x 4.75 x 20% = 5.7 Gb/s. As this value is higher than the one-time peak (4.75 Gb/s), we have considered it for our calculations.

Each DU is connected to an XGS-PON ONT, which means there will be nine XGS-PON ONTs (54 RUs / 6 RUs per DU = 9 DUs). Although it would be possible to connect all nine ONTs to the same PON, this is not recommended in order to avoid oversubscription and congestion. The optimal number of PONs in this case would be calculated as the throughput from all DUs considering a statistical gain of 30% per PON divided by the maximum throughput on XGS-PON (8.2 Gb/s):
Number of PONs = roundup [(9 DU x 5.7 Gb/s) x (1-30% gain) / 8.2 Gb/s] = 5
The midhaul throughput calculation in the stadium is summarized in the table above.

# of RU	6	
# RUs per DU	1	RU and DU are collocated
# of DUs	6	
Peak rate per DU	3.65 Gb/s	Based on 3.5 MHz, 100 MHz spectral bandwidth, mMIMO 16x16
∑ avg. rates or DU	0.73 Gb/s	= 3.65 Gb/s x 20%
Throughput per DU	3.65 Gb/s	= max (3.65 Gb/s, 0.73 Gb/s)
# of ONUs	6	Equal to #DU
+ of PONs	2	= roundup [(6 DU x 3.65 Gb/s x (1-30% stat.gain) / (8.2 GB/s per PON)]

Table 2: Summary of midhaul calculations outside the stadium

Dimensioning throughput in the surrounding urban area

In the urban area sites, a single cell site described above has a peak data rate of maximum 3.6 GHz. Each cell site has three sectors and an F1 midhaul interface to the edge data center. In this architecture there is no fronthaul, as RUs and DUs are collocated.

Midhaul

Applying the same calculation method as in the stadium midhaul, the throughput dimensioning for midhaul in urban area is summarized here:

For a highly available midhaul network, each XGS-PON (5+2) can be protected with a Type-B protection. Therefore, we use 2:n splitters and two fibers diversely routed into the feeder section. The 2 x 7 XGS-PON interfaces will be spread over two XGS-PON line cards. This is deployed from a single access node, for example the ISAM FX/DF/SF or Lightspan FX/CF.

Dimensioning latency

There are two different latency requirements that need to be investigated: the scheduling latency and the application latency.

Scheduling latency

Scheduling latency is the time that a system is unproductive because of scheduling tasks. Both 5G uplink schedulers and PON use a “request-grant” mechanism and algorithms to recover from error transmissions, which causes latency.

In 5G, the request is sent from the user equipment (UE) to a radio resource scheduler. When data arrives at the UE, the UE first determines if it already has a 5G uplink grant. If it does not, the UE waits for an opportunity to transmit a scheduling request, which typically comes in defined intervals.

The radio transmissions over the air interface often occur in a harsh wireless environment. Wireless signals are easily degraded due to path loss and interference and transmission errors are far more likely at the cell edge. To overcome transmission errors, 5G uses automatic repeat request (ARQ) and hybrid automatic repeat request (HARQ), which is ARQ in conjunction with a forward error correcting (FEC) algorithm, to quickly retransmit the data in larger physical resource blocks. This retransmission function requires a very low latency and round-trip time (RTT) of < 200 μs for low-level split (fronthaul) architectures like CPRI and eCPRI.

For a higher layer split (midhaul), the latency originates from the transmission control protocol (TCP) slow start and requires 8 ms RTT.

Application latency

For some 5G applications the target RTT is less than 1 ms (autonomous vehicles, robotics, etc.). To adhere to this latency requirement, several domains need to change: new radio frame design, new user devices, new base station hardware and the location of the application server. The latter in practice necessitates local content and a local cloud. Edge computing offers cloud computing capabilities and an IT service environment at the edge of a network. This allows hosting applications in these distributed locations, closer to the end user. This directly improves network performance in terms of latency and throughput which benefits the user experience. Operators also benefit from the efficient redistribution of the load on the transport network and an opportunity to monetize advanced services and the hosting of partner content.

The “Cloud X” approach defined by Bell Labs is a way to segment and analyze network latency targets. Each segment supports service groups that require similar performance targets. For example, Cloud 1 has a latency < 1 ms for motion control and factory automation, while Cloud 250 has a latency of 250 ms for internet services like SMS, email, etc. Application

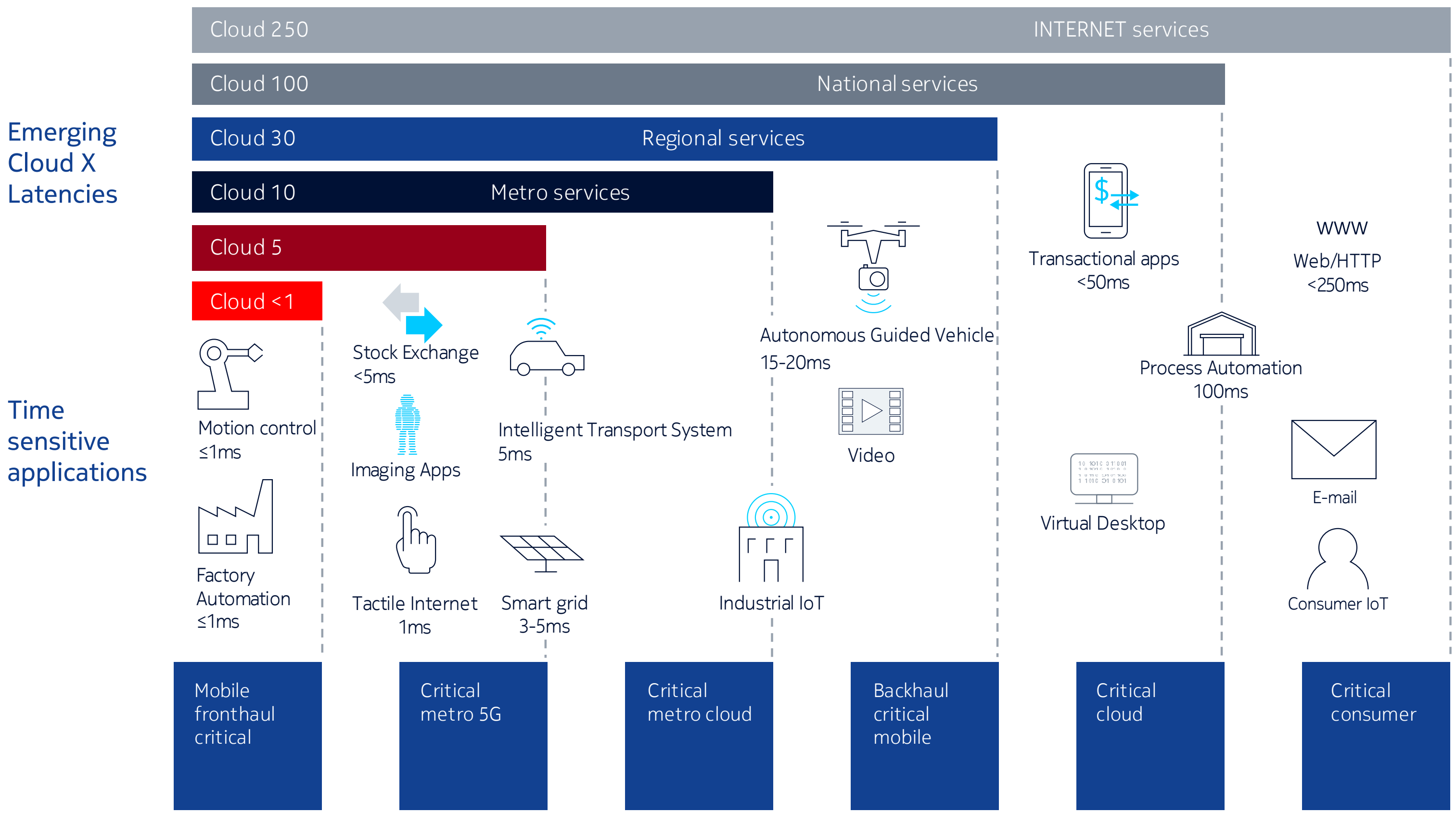


Figure 2: Application examples characterised according to CloudX

examples characterized by Cloud X are presented in Figure 2. The network is split into zones (or slices) each delivering its own set of services.

In our case study we have considered solutions for Cloud 10 (for example, automated vehicles and drones at the stadium). Cloud 10 applications are installed in edge locations. If a need arises for applications in the stadium that require even lower latency (Cloud 1 or Cloud 5), then a separate application server would be installed closer to the end user, for example in the telecom room of the stadium or 'cloudlet'/ mini data center in a street cabinet. However, we have not considered this case for two reasons: first, there are no such low-latency applications envisaged for use at the stadium; second there is no impact on the midhaul transport because the application server would be at the stadium and midhaul transport would not be used to deliver these applications.

The F1 midhaul network can use a Software-Defined Access Network (SDAN) solution to slice the PON network and further optimize connectivity for different service types. Network slicing is implemented in the Nokia OLT and Nokia Altiplano (SDAN controller).

The latency required on a PON for midhaul is the lowest value originated by all latency requirements (scheduling latency and application latency), which is 8 ms. Since Cloud 1 and Cloud 5 are located at the stadium, the midhaul should only support Cloud 10. This requirement is met on PON networks because the delay on a PON is never higher than 2 ms.

Dimensioning time synchronization

5G has increased the clock precision required for specific service clusters. This clock precision, based on existing commercial GPS, is not the optimal solution as it requires line-of-sight to the sky and can be susceptible to jamming. In addition, deploying high-precision GPS at the base stations is expensive given that 5G base stations have a high density. Therefore, the optimal synchronization solution for 5G is to use transport networks with SyncE and IEEE 1588v2 to provide high-precision clocks for base stations.

To enable seamless handover between adjacent radio stations, 5G requires precise phase alignment of ±3 μs between radio stations. Each 5G base station should, therefore, be accurate compared to a common grandmaster of ±1.5 μs. Deducing the time for end-application and short-term holdover (the ability of the system to maintain the synchronization within acceptable limits when the source of synchronization is lost), leaves a maximum 1.1 μs absolute time error for the transport network.

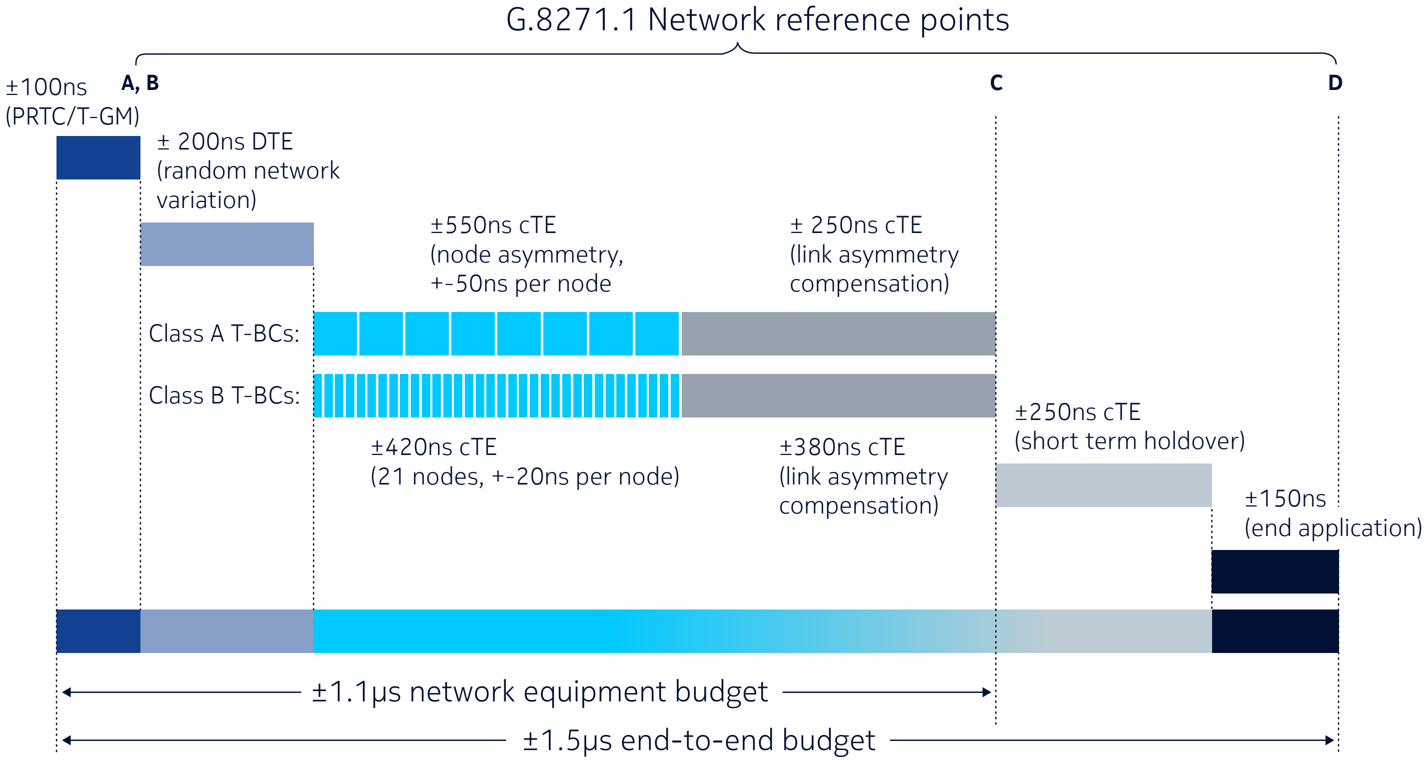


Figure 3: G8271.1 Network Reference Points

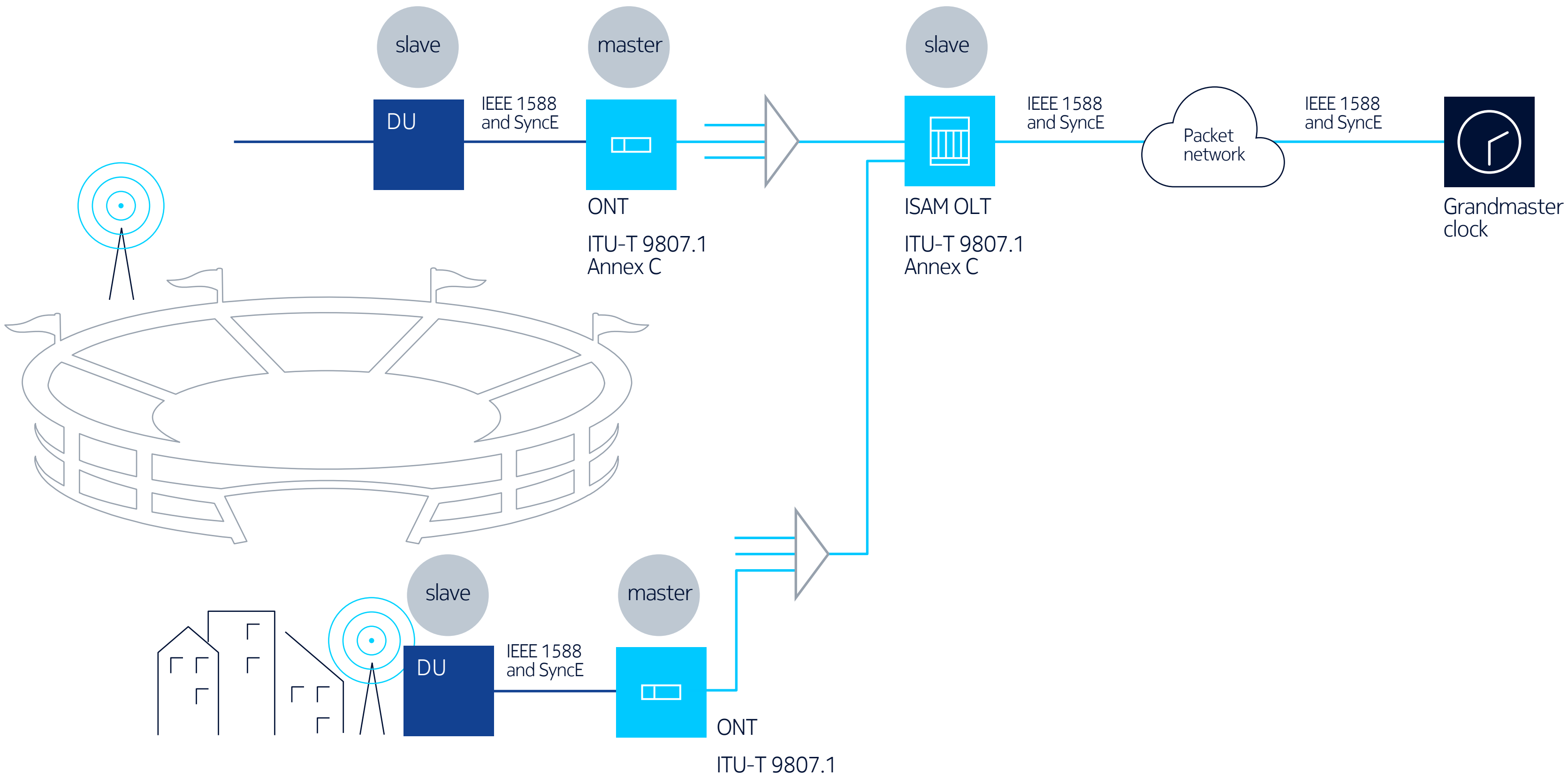


Figure 4: ITU-T G.9807.1 (XGS-PON) – definition of accurate time distribution over PON

To ensure clock precision requirements over a PON network, each node between the grandmaster (T-GM) and the radio unit (end application) needs to be a boundary clock (T-BC). A boundary clock node has two or more ports. One port is in a slave state, getting time from a grandmaster clock. All other ports are in a master state propagating sync messages received on a slave port to downstream slaves. PON requires hardware (clock chip) support to ensure time of date precision with a maximum error of 100 ns.

In our example, network-based timing distribution uses IEEE 1588v2 Precision Time Protocol (PTP). The OLT can be a boundary clock T-BC ITU-T G.8273.2 Class A using BITS or SyncE (EEC ITU-T G.8262) as the frequency source, in combination with PTP G.2875.1 profile (layer 2 Ethernet in multicast) with specific ONT types using standard ITU-T defined inter-working functions (IWF) between OLT and ONT.

Conclusion

In this study we have shown how a PON network can be used for Broadband Anyhaul in one of the most likely early 5G scenarios: a sports stadium and the surrounding urban area.

- In this case, fronthaul cannot be addressed with XGS-PON due to the high throughput requirements, but future PON technologies, like TSN (Time-Sensitive Networking) grade 25G PON could be a fit.
- PON is very attractive for midhaul, meeting the throughput, latency and synchronization requirements, while at the same time delivering cost-efficiency and convergence of residential, business and transport services on one network.
- Network slicing with SDAN can be used to further optimize the connectivity for each service type, including mobile midhaul.
- Nokia PON portfolio is 5G-ready and can deliver Broadband Anyhaul with a variety of options, different form factors for anywhere deployment, in a software-defined or traditional environment.

Acronyms

5G	5th generation mobile networks
ARQ	Automatic repeat request/query
BITS	Building Integrated Timing Supply
CPRI	Common Public Radio Interface
CU	Central unit
DU	Distribution unit
eMBB	Enhanced Mobile Broadband
FEC	Forward error correcting
FTTH	Fiber-to-the-home
GPS	Global Positioning System
HARQ	Hybrid automatic repeat request
IWF	Inter-working functions
LTE	Long-term evolution
MEC	Multi-access edge computing
OLT	Optical line termination
ONT	Optical network termination
PON	Passive optical networks
PTP	Precision Time Protocol
RAN	Radio access networks
RTT	Round-trip time
RU	Radio unit
SDAN	Software-Defined Access Network
SMS	Short message service
SyncE	Synchronous ethernet
T-BC	Boundary clock
T-GM	Grandmaster clock
TCP	Transmission control protocol
TSN	Time-Sensitive Networking
UE	User equipment
XGS-PON	10G symmetrical PON

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