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The evolution of microwave transport - enabling 5G and beyond

White paper

As 5G is deployed, mobile network transport networks will need to be evolved to meet multiple new demands ranging from network densification and network slicing to RAN decomposition and network function virtualization. While transport will depend on a mix of technologies including IP, fiber and broadband, new microwave capabilities will offer compelling and cost competitive solutions to continue to play a vital role in mobile transport networks of almost all CSPs.

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Executive summary: Why microwave transport must evolve

In the next three to four years, communications service providers (CSPs) will run backhaul transformation projects to meet the needs of 5G Radio Access Network (RAN) service provisioning. With mobile data traffic continuing to grow rapidly (40-fold between 2014 and 2020) and the imminent connection of 50 billion Internet of Things (IoT) devices by 2025, CSPs are being driven to rethink their existing transport network architecture.

Today, IHS estimates that more than 50 percent of base stations are connected by microwave. Microwave technology will evolve with new compelling and cost competitive solutions to continue to play a vital role in mobile transport networks of almost all CSPs.

According to Marcus Weldon, Corporate Chief Technology Officer and President of Nokia Bell Labs: "5G, with a much broader set of applications, will drive higher user data rates as well as ultra-low latency and extreme availability requirements. Capacity needs initially will be up to 10 Gbps per site but later as high as 100 Gbps, and latencies of the order of 1 ms. This poses new challenges for transport network designers and planners. Additionally, RAN densification and further RAN architecture decomposition will require much more flexible transport networks. Microwave radio has reached new capabilities (10 Gbps and beyond) and with the increased flexibility (SDN readiness), it can fulfil the new 5G requirements. In the near future we will also see D-band microwave with up to 100 Gbps capabilities used for fast rollout of 5G small cells operating with millimeter waves at 24-39 GHz."

The introduction of 5G and related network slicing will drive further densification of the network and increase the number of service access points. This will create a need for mesh connectivity transitioning from a predominantly hub and spoke access topology environment today.

The operation of virtual network slices will require a move to digital operations using Software-Defined Networking (SDN) to provide network programmability. 5G will also enable new revenue streams based on fast service deployment with a short life cycle, underlining a further need for digital operations.

Technology providers are working closely with carriers and enterprises on evolved transport network strategies to cope with new capacity, connectivity and latency requirements, considering the many lessons of previous technology shifts.

Other strategic challenges to be considered include:
1) Converged networks and the transition to a programmable transport network to support the slicing concept
2) Meshed (or partially meshed) topologies
3) Traffic Engineering (TE)
4) Shorter service activation cycles (from days to hours to minutes)
5) Greater automation.

Network transformation will affect microwave solutions deployed for 3G and the early stages of 4G probably more than any other transport technology. The integrated evolution of radio access and transport can potentially add unique value for a CSP. The substantial installed base of microwave will inevitably be replaced over time in favor of new microwave solutions designed for 5G or, in some instances, fiber. Nokia has developed appropriate solutions and tools to help optimize budgets during backhaul network upgrades. Both CAPEX and OPEX are considered because, while a program of network 'renovation' is costly over many years, CSPs will need to manage their investment within the constraints of their normal annual budget. A common goal is to provide innovative and technologically advanced solutions within a constrained Total Cost of Ownership (TCO) to match budgets.

This white paper discusses Microwave Transport Network evolution from strategic and operational perspectives, bringing tangible examples and a clear direction for CSPs and enterprises planning this next strategic step.

Tightly merged core, transport and radio access will deliver best performance

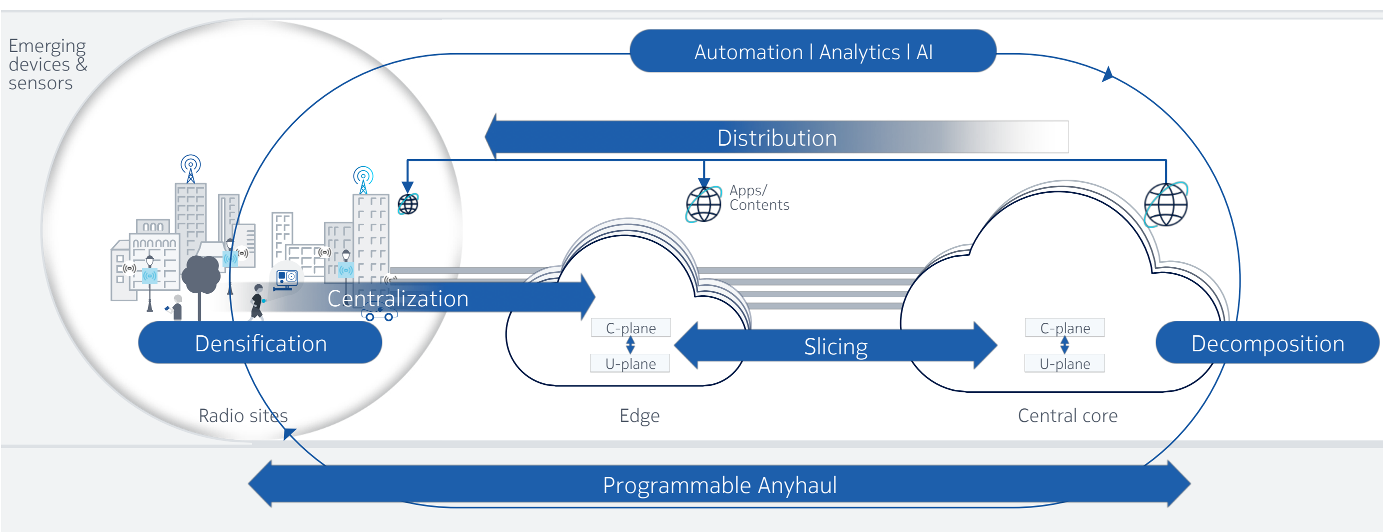
5G is more than just an innovative radio technology using new spectrum. It introduces a new approach to network architecture that builds on new concepts such as densification, decomposition of network functions (e.g. the separation of user and control planes), programmable transport, end-to-end automation and orchestration, and network slicing to enable new service business models. A complex interworking of different network domains, technologies, components and services will be needed.

CSPs traditionally treat the core, transport and radio access networks independently and integrate the different infrastructure parts only after deployment. However, in new 5G scenarios, post-deployment integration costs, time-to-market and the risks of degraded service quality would increase dramatically.

Without cross-domain design and pre-deployment integration, CSPs risk missing new business opportunities created by 5G. Business-critical applications depending on ultra-reliable low latency communication and extreme network reliability can only be delivered with the seamless, error-free interaction of radio, transport, core, data centers and management systems.

Evolution strategies such as Nokia Future X (see figure 1) allows CSPs to address the interworking complexity of new 5G scenarios.

Figure 1. The Nokia Future X solution provides CSPs with the opportunity to take advantage of the promise of 5G. Built on open systems with pre-deployment integration, Nokia 5G Future X minimizes the need for the time-consuming and costly post-deployment integration



5G Future X

- Combines an end-to-end portfolio covering massive scale access, converged edge cloud, cloud-native core, programmable and scalable “Anyhaul” transport and process automation
- Uses cross-domain cloud-native functions to enable rapid deployment of virtualized functions across a distributed cloud infrastructure to simplify service scaling, shorten time to market and deliver cost efficiencies across radio, core and transport networks
- Takes advantage of cross-domain services and tools, where the technology partner works with customers to tailor and optimize network design and deployment based on evolving business needs
- Leverages product development processes that ensure security and privacy are built in across the network.

Strong integration between radio access and transport (e.g. microwave) domains is expected to be more and more required for CSPs, due to the rising network complexity network slicing introduced by 5G. It could bring improvements especially in the following areas:

- Serviceability, thanks to simple and automated dynamic service provisioning with end-to-end fulfillment and troubleshooting. This is becoming more relevant with the advent of network slices, which would need to be dynamically associated to the programmable transport pipes.
- Traffic engineering, thanks to transport resource optimization considering also RAN needs. A close parameter exchange between RAN and transport could be beneficial for the end-to-end requirements. The base-station, for instance, being aware of the transport networks, can enable better networking performances (e.g. alternate path switching) to meet Service Level Agreements (SLAs) and better quality of experience.
- Optimization of specific transport technology (e.g. microwave), reducing overall TCO and improving performance.

5G “Anyhaul” to connect, automate and deliver new multiple network services

5G will place high demands on the transport layer, including very low latency, high reliability, increased efficiency, extreme bandwidth and many devices. This is a dramatic evolution from the requirements of previous mobile generations.

Network densification, virtualization and automation bring unprecedented pressure on CSPs to upgrade or replace their existing network infrastructures, to evolve their capabilities and fundamentally rethink their network architectures. The virtual functions of a RAN are distributed over multiple platforms: some in the Cloud, others close to end users, raising the need for a new, agile way to connect them across the network while guaranteeing Quality of Service (QoS) and network reliability.

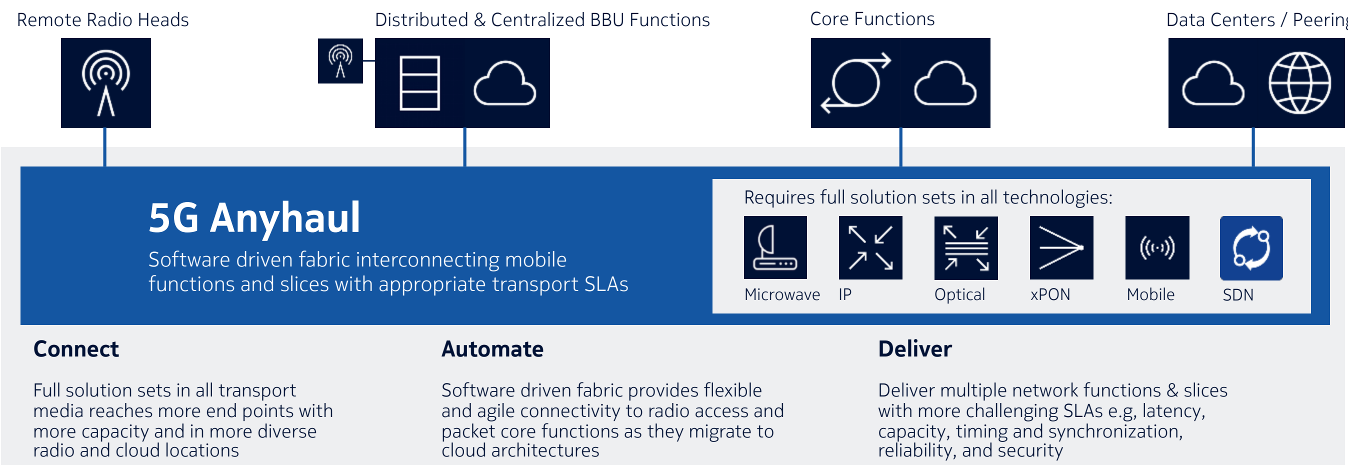
The need for an end-to-end approach

To support a wide range of 5G applications and use cases, transport must be a multi-service capable, highly flexible fabric to address greater coverage, connectivity and availability, along with dramatic capacity and latency improvement, and all of this must be cost effective.

The optimal transport solution will vary from CSP to CSP. It must integrate the radio access and packet core functions to support the breadth of 5G requirements while optimizing the re-use of existing networks.

To address these requirements, CSPs need a holistic approach that considers all their needs as well as their accessibility to all types of transport technologies. Such a holistic approach is shown in figure 2.

Figure 2. The 5G Anyhaul solution allows CSPs to optimize the evolution of their transport network and enable new mobile transport layer capabilities for 5G



CSPs with a technology partner that offers a comprehensive mobile transport portfolio (fiber, copper, microwave), will benefit from more effective and easier integration and fast deployment to accelerate their migration to cloud and 5G. The portfolio would also need to provide extreme flexibility and ease of integration through an open, programmable network architecture with service assurance. Any solution must offer CSPs the agility and flexibility to respond to changing market demands and conditions.

Efficient evolution to 5G will exploit LTE networks, especially the higher performance of 4.5G and 4.9 technologies. However, 5G is not just another incremental step in network performance. It brings deep transformation affecting multiple dimensions by providing a common core for several radio technologies (cellular, Wi-Fi, fixed), multiple services and network CSPs[1].

5G will enable many new services, including enhanced mobile broadband, augmented reality, mission-critical communications, creating an unprecedented traffic mix that will require dramatically improved performance. For example, throughput will need to rise ten-fold (10/25 Gbps for F1* and backhaul interfaces) and latency will need to become ultra-low latency down to 1 ms end-to-end.

Densification and RAN decomposition add to the complexity challenge

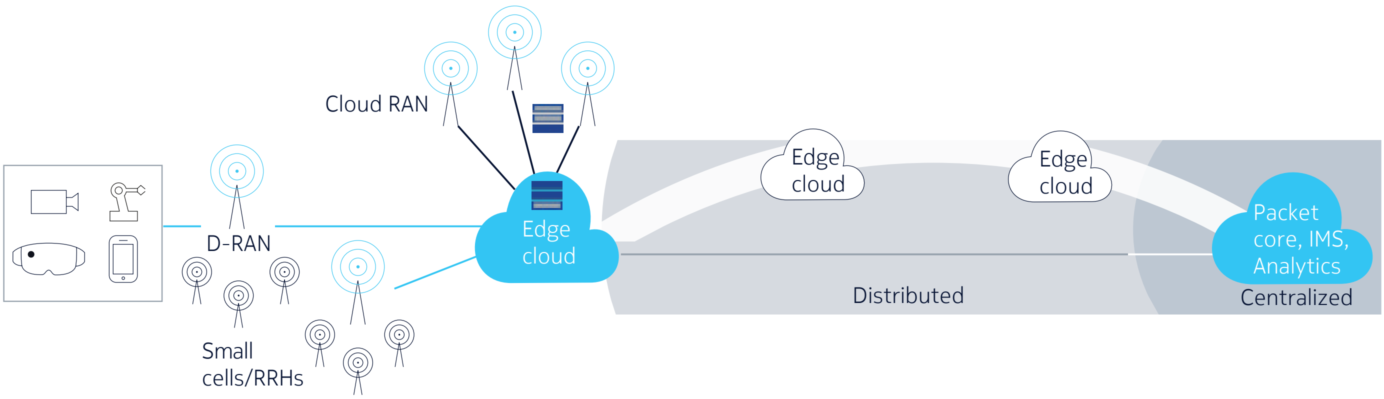
High reliability densification (>99.999 percent) will mean more sites to be connected, with heavy implications for transport. For instance, in a typical deployment, a macro cell could act as a pooling site for small cells in its coverage area. High user density (> 150,000 subs/km^2) implies increased connectivity between base station sites with different connectivity technologies. Furthermore, connectivity will continue to evolve, requiring cell sites transport connectivity to be more flexible and dynamic.

RAN decomposition is a further consideration. Virtual RAN functions will be distributed over multiple platforms and new interconnectivity ("X-Haul") interfaces are created. Cloud shift and centralization of some functions is TCO driven when there is the possibility to optimize the network; other functions are moved closer to the end user to better comply to stringent low latency requirements.

*F1 is the interface between cloud RAN distributed and central units.

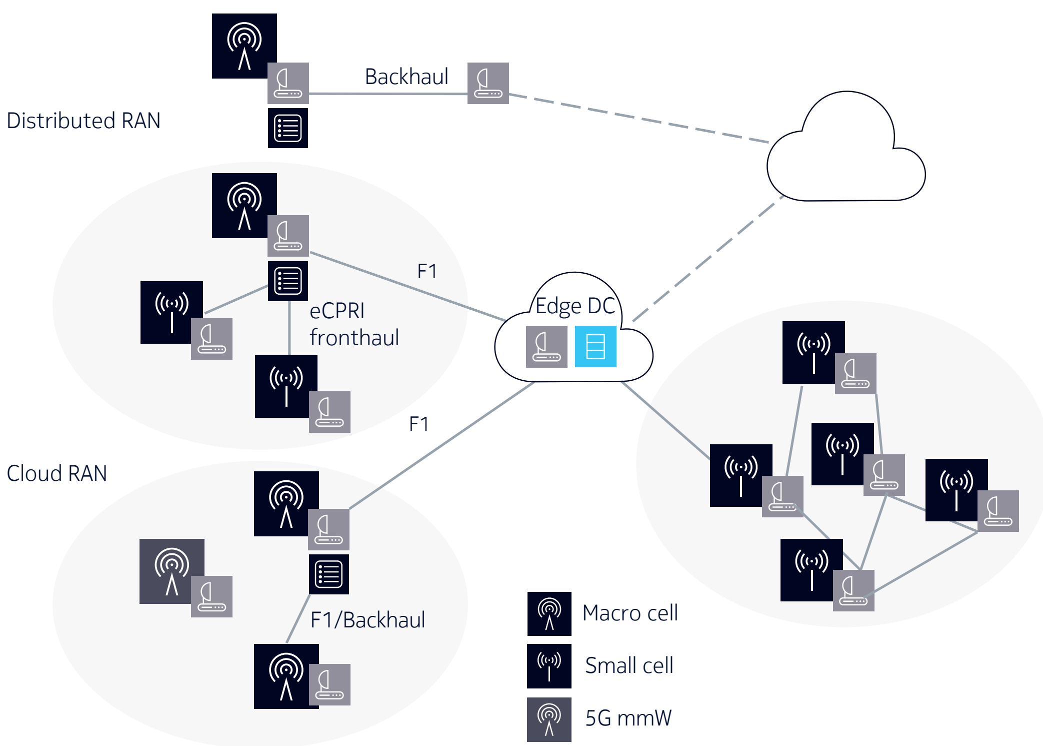
Such flexible and complex networks will require automation to allow granular end-to-end traffic engineering and to satisfy different SLAs through automated and programmable transport pipes in the shape of network transport slices that dynamically adapt to changing conditions/requirements (see figure 3).

Figure 3. Transport network slicing will create pipes that can meet many different SLA needs



RAN decomposition and densification will require the transformation of transport connectivity from simple hierarchical tree topologies (classical backhaul, connecting the access points to the core) to a more complex ring/meshed infrastructure. This new "Anyhaul" concept (fronthaul/midhaul/backhaul convergence) will serve a variety of use cases within the same network as shown in figure 4. This transport network evolution and the demanding 5G targets will dramatically increase capacity, connectivity and agility requirements.

Figure 4. A new ring/meshed infrastructure will be needed to meet the needs of RAN decomposition and densification



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Wireless transport connectivity is a key 5G enabler

Microwave technology has served multiple generations of mobile networks for decades. To a large extent, LTE's success relies on microwave technology, which provides hundreds of megabits per second of capacity with short roll-out times.

Fiber optic presence in transport networks has increased in the past years and this trend will continue as CSPs exploit the technology's advantages. Nevertheless, wireless transport connectivity is a key enabler for 5G use cases. Consider the following:

- Fiber may not be available in suburban/rural areas. Also, in urban areas, if the CSP is not incumbent, fiber leasing may be too expensive, especially in view of the evolution towards 10/25 Gbps interfaces
- In current mobile networks, microwave is used in more than 50 percent of cell sites. Providing fiber to these many sites would be a considerable, time and costly undertaking
- When a fiber Point of Presence (PoP) is a few hundred meters away from the radio access point, TCO evaluation tends to favor microwave connectivity: fiber trenching costs are unlikely to reduce over time
- In dense urban environments it is common to have fiber access at building level, but not at street pole level
- Microwave technology can address 5G's challenging capacity and latency requirements. Propagation-medium induced latency depends on the density of the medium, so the latency of a wireless connection is fundamentally lower than that of a fiber cable of the same length. Equipment-induced latencies must, of course, be added into the equation.
- Mission-critical applications (e.g. public safety use cases) require high resiliency network performance. Wireless connectivity is generally more reliable than fiber during major events such as earthquakes, fire, or simple road maintenance. Moreover, in these cases, the recovery time is much faster with a microwave connection.

A North American Operator Planning 5G over Microwave

Many vendors and operators are convinced that microwave has much more to offer in 5G than with 4G. Recent discussions with a major North American operator revealed to Nokia the importance of microwave solutions for existing and future mobile networks.

The following quotes illustrate why:

DENSIFICATION: "... a subset of our wireless network is fed by microwave supporting macro-sites; more and more we are trying to fiberize them. These sites then become access, then distribution points and we can then expand further into the respective area."

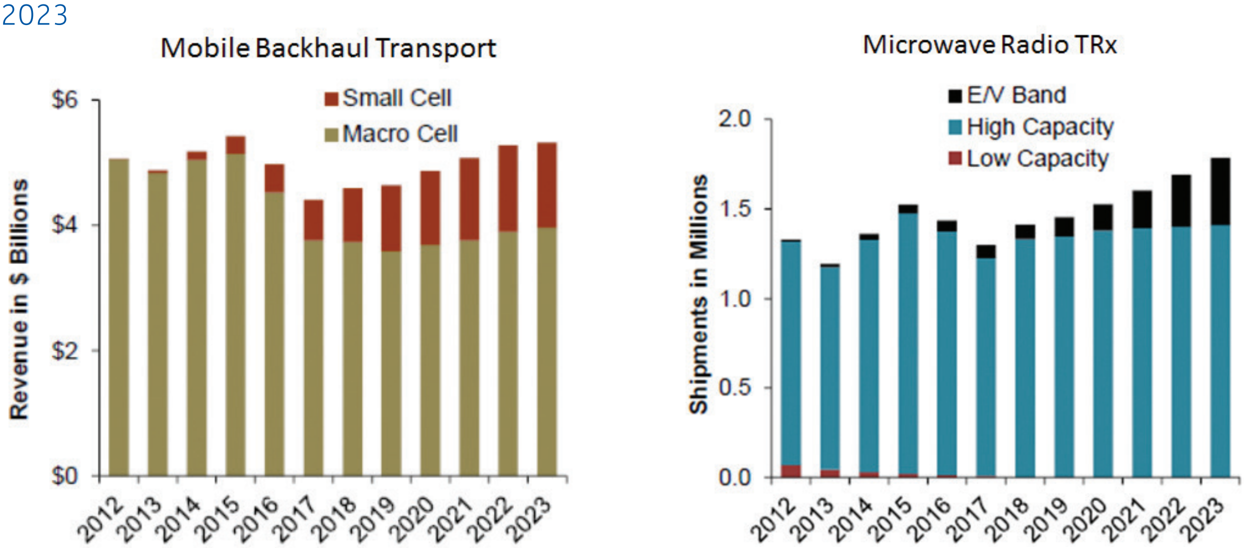
MICROWAVE ADVANTAGE VS. FIBER: "...if we can start generating revenue earlier by using microwave, this also helps the business case and is hence where microwave can be a strong solution. There are also risks of losing that customer if we can't deliver their network."

MICROWAVE AS ENABLER OF 5G: "5G is coming ... with densification, customers may be closer to the base station; we may have to use microwave; we kind of have a vision of fiber everywhere, but we're not seeing it yet developing as we'd hoped, so having microwave in the toolbox will be important."

5G will increase the need for microwave transport deployment

Microwave technology has the undisputed lead in mobile backhaul transport today. Based on several industry reports and predictions, microwave will also play an important role in the future.

Figure 5. Microwave technologies will play a continuing and important role in mobile backhaul transport. Source: Dell'Oro Group: Microwave transmission and mobile backhaul five-year forecast report 2019 - 2023



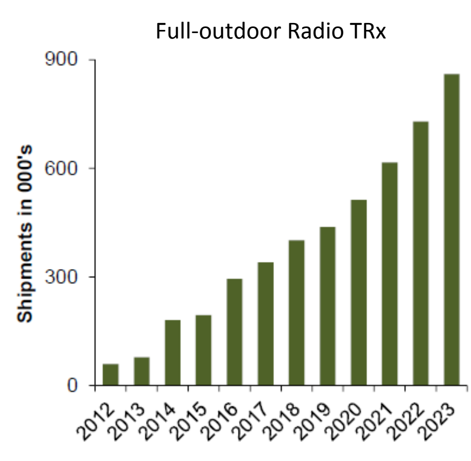
According to Dell'Oro (see figure 5), the mobile backhaul transport market will return to growth again in the next five years thanks to 5G and small cell deployments. This will result in a US $5.3 billion market by 2023. The importance of microwave technology will be significant also in the 5G era. The increasing demand of small cell backhaul will also drive the increasing introduction of E-Band and D-Band microwave systems as well. 5G will also increase the use of other fronthaul transport options, bringing still further opportunities for microwave technology.

According to predictions in the microwave transport segment, packet microwave will be the only sub- technology which will show large growth in the next five years, driven by rising demand for full outdoor systems and high capacity E/D-Band systems.

Regarding the architecture, the number of full-outdoor systems will increase in the coming years as the need of T1/E1 interface traffic decrease and the full-outdoor systems can be connected directly to the cell-site routers to minimize the cost of a 5G site (see figure 6).

Beyond this, to meet 5G requirements, multiband systems that carry both a standard frequency and a millimeter frequency over a single antenna will be deployed in more locations. These multiband systems will extend the use of E-Band systems into routes that require longer reach or areas with imperfect environments for E-Band performance.

Figure 6. Growth in the delivery of Full-Outdoor systems



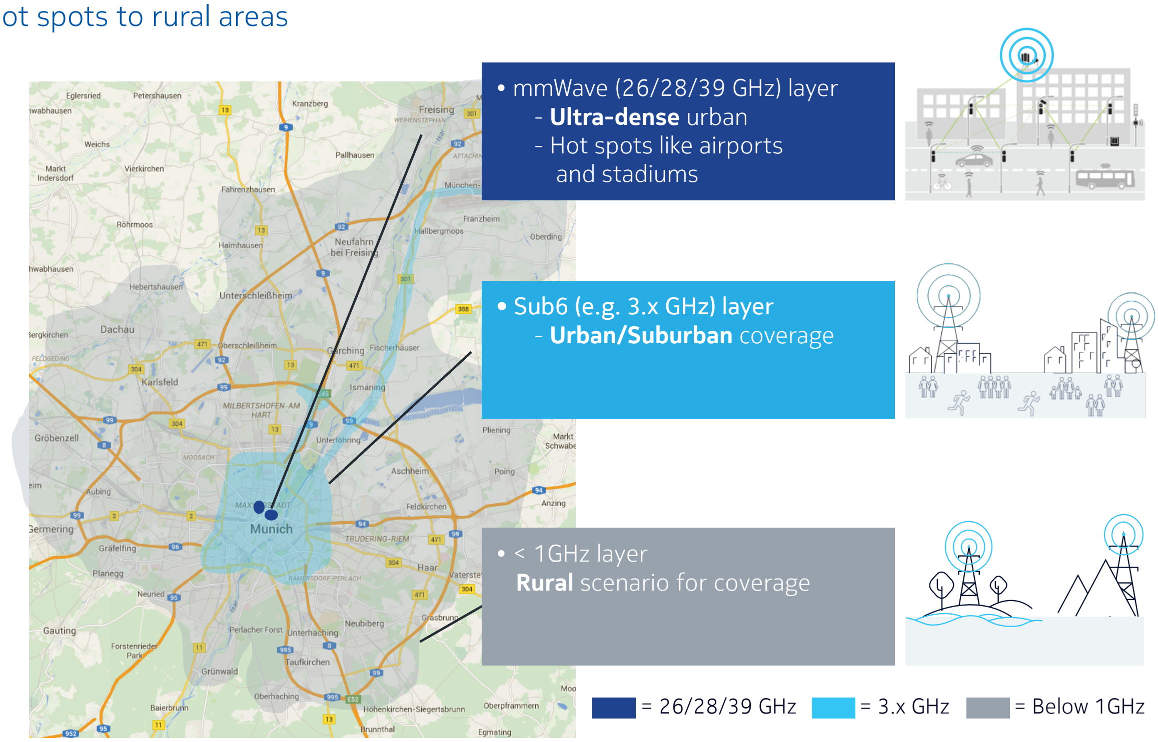
According to the IHS Markit “Microwave Market Outlook 2019” report, microwave technology – now the dominant backhaul solution – will also play a key role in 5G deployment” said Richard Webb, Director of Research and Analysis in Service Provider Technology at IHS Markit. “Microwave vendors will be able to deliver radio products that meet 5G requirements, including the following: multi-gigabit capacity and stringent latency requirements; a unified approach to 5G transport, with the seamless integration of the different backhaul layers; a single managed environment; and the adoption of SDN, to copy with the evolution into autonomous, cloud-based solutions. Fiber will not be available at every site, so other technologies will need to be considered. It is clear microwave will continue to be essential, not only to backhaul the long-tail of LTE/LTE-A, but also right into the 5G era.

Microwave solutions for different 5G scenarios

Wireless transport solutions must accommodate different characteristics and requirements considering possible 5G scenarios in different geographical areas, see figure 7.

- In ultra-dense urban areas or hot-spots such as crowded squares, airports and stadia, 5G networks will be deployed with the radio access millimeter wave layer (26/28/39 GHz). Very high capacity backhaul is needed (10 Gbps and above) and the transport link lengths are always less than 1 km
- In the urban/suburban scenario (up to 7-10 km link distance) the access layer will be based mainly on sub-6 GHz frequencies with connectivity requirements that are still quite demanding in terms of capacity (5-10 Gbps)
- In rural settings, where the geographical area coverage is larger, the access network will be based on frequencies below 1 GHz. The transport network will need to backhaul up to 2 Gbps and the link lengths commonly exceed 7-10 km

Figure 7. Microwave transport must meet the needs of widely different deployment locations from dense urban hot spots to rural areas



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Current and future microwave solutions for 5G

To meet the needs of CSPs, global suppliers need to be able to provide end-to-end capabilities to fulfil access, transport and management demands. A microwave portfolio needs also to be fully integrated into an end-to-end vision and provide the best fit for all scenarios. Future microwave solutions with very small form factors will be even more integrated with RAN equipment.

Figure 8 shows how microwave/millimeter-wave can address the primary 5G use cases.

In today's frequency bands used for RAN backhaul (6-42 GHz), several vendors can provide transceivers capable of 2.5 Gbps in a single box (thanks to 4096 QAM modulation schemes in 2 x 112 MHz frequency channels).

To meet the increasing 5G capacity requirement, new solutions for optimizing the use of spectrum are now available. Carrier aggregation (using multiple bands on the same link), more powerful and efficient power amplifiers that enable the use of wider channels and the availability of millimeter-wave spectrum are key solutions.

Figure 8. Microwave and mmWave transport can meet the needs of the main 5G use cases in different locations

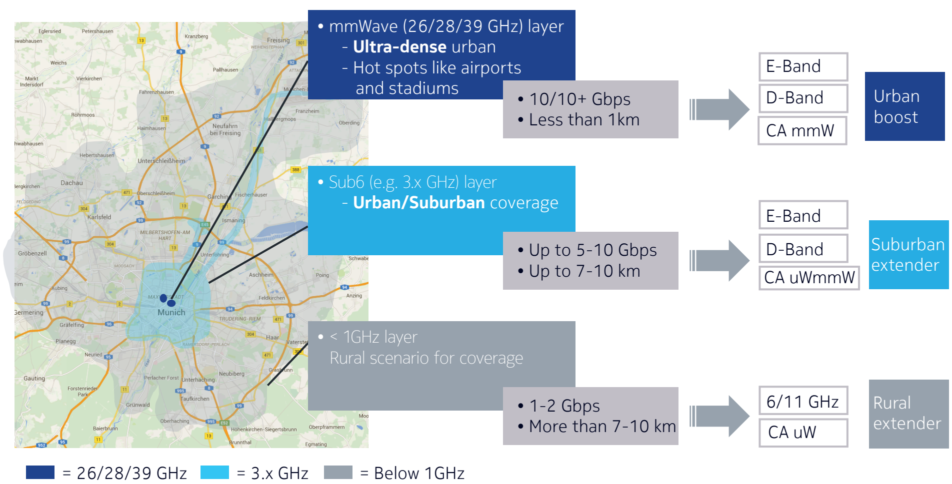
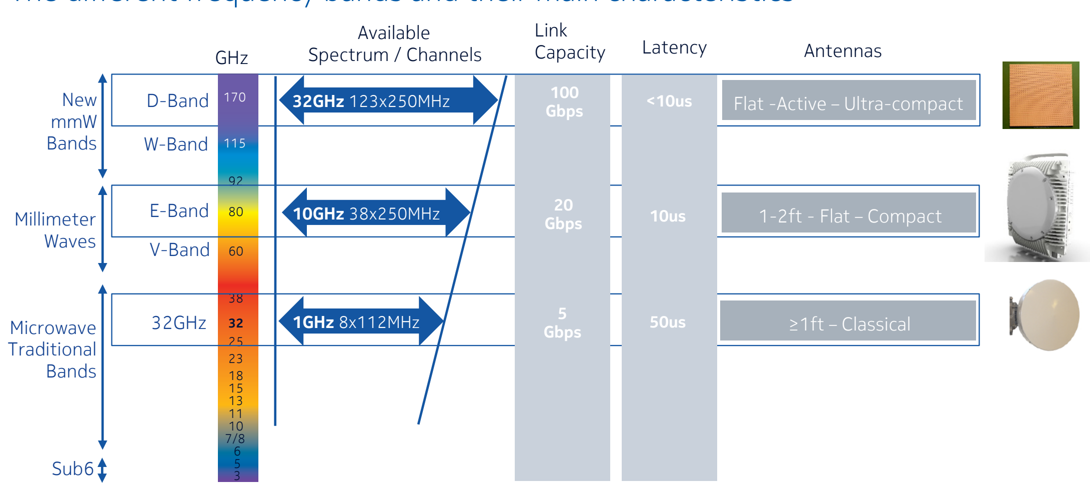


Figure 9. The different frequency bands and their main characteristics



The higher the frequency, the larger are the available channel spacings, hence offering more capacity with lower latency (see figure 9).

E-Band (80 GHz) millimeter wave technology has evolved from the bulky and expensive 1 Gbps capable devices, launched more than a decade ago, to new and more powerful equipment, capable of 10 Gbps in the range of a few kilometers. Some microwave vendors have also introduced cross polar interference cancellation (XPIC) to significantly extend E-Band coverage or to allow a doubling of capacity for the same link distance.

Low visual impact is a key factor to facilitate deployment in dense urban environments. Nokia, for example, has integrated the antenna with the radio unit, achieving a very small form factor for low TCO.

Figure 10. Integrating the antenna with the radio unit achieves a very compact unit suitable for deploying in dense urban environments

Current E-Band based solutions can satisfy the initial wave of 5G introductions that require up to 10 Gbps transport capacity and 20 microsecond latency in urban environments. By combining E-Band with a traditional microwave frequency band (6-42 GHz), it is possible to achieve longer distances and preserve the usual high availability for the most valuable traffic. Combined with 100 percent efficient carrier aggregation it is possible again to achieve up to 10 Gbps bidirectional capacity.

Carrier aggregation represents a significant breakthrough for microwave technology, allowing the optimal use and combination of available spectrum, strongly improving the performance of microwave links and providing TCO optimization thanks to the availability of a range of dual band antennas.

Trends in spectrum

The telco industry has already started to consider the possible use of frequency bands above 100 GHz for the transport segment of the network.

Recent activities[2,3,4,5,6] indicates the highest interest in D-Band (130-174.8 GHz) and W-Band (92-114.25 GHz). While W-Band is viewed today as a likely extension of E-Band (71-86 GHz) because of the similar propagation behavior, the peculiarities of D-band enable innovative approaches in equipment design.

It is expected[7] that D-Band radio solutions will be for capacities of several Gbps over hop lengths up to 1 km. D-band technology will allow fiber-like capacity (Nx25 Gbps) at ultra-low latency (sub 10 microsecond) and ultra-small form factor with antennas just a few square centimeters in size (figure 11).

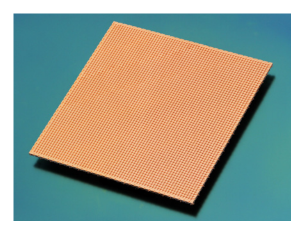


Figure 11

Moreover, the very small form factor will aid the integration the radio and the antenna, and between transport and access products, enabling new network topologies such as point-to-multipoint and mesh connectivity in conjunction with beam-steering.

D-Band spectrum is shown in figure 13. From the total block of 45 GHz (i.e. from 130 to 174.8 GHz), only some portions of the spectrum will be available[6], because part will be reserved for different services. This arrangement is considered an optimized trade-off between very wide channels and spectrum efficiency to allow compact and low power consumption solutions for Fixed Wireless Access (FWA) and ultra-high capacity systems for backhaul and fronthaul applications.

The very small D-Band antenna size enables a new approach, called flexible Frequency Division Duplexer (fFDD). This method is implemented using two antennas per end, one for TX and one for RX, avoiding the need for a duplexer filter. An example of this approach, is considered in[8] an EU H2020 project, driven by the major CSPs and microwave vendors such as Nokia (see figure 14).

Comparing classical microwave systems operating in traditional frequency bands with future ultra-compact D-band systems it is evident which step function improvements are possible both in capacity and latency. With a size of just a few centimeters square, a flat-active D-band antenna outperforms a classical 60 cm diameter standard antenna currently used in mobile networks.

The shift towards higher spectrum bands to provide large and unused spectrum is well aligned to future capacity requirements and with the densification needs: ultra-dense transport networks with short links. Mesh connectivity will then guarantee the resiliency mandatory for specific SLAs, including mission and business critical applications.

Figure 12. New network topologies will be possible through the integration of radio and antenna and with transport equipment

Figure 13. Not all D-Band spectrum will be available to CSPs

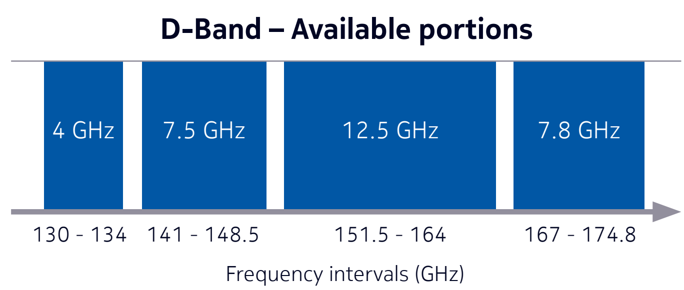
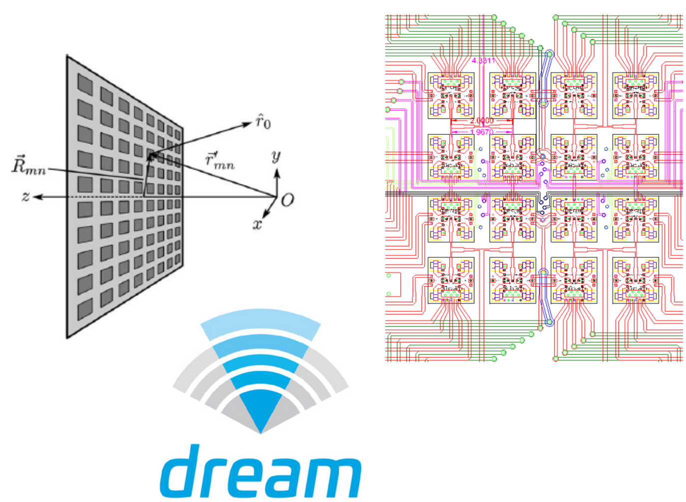


Figure 14. Study of D-Band phase array antenna and beam steering approach



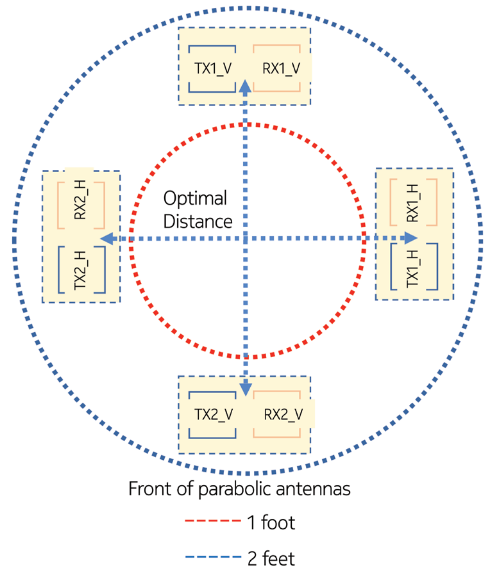
D-band challenges and solutions

One of the most challenging aspects of a D-band solution is the antenna and associated radio architecture.

Multiple Input Multiple Output in Line of Sight (Los-MIMO) increases link capacity by using more than one antenna at transmitter and receiver ends of the link. To achieve significant capacity increase, applying MIMO to point-to-point (PtP) microwave systems relies on optimal geometric spacing between antennas. Optimal antenna spacing is usually the key issue in lower frequency bands, but not in D-Band, where it is close to 50 cm for hop lengths up to 500 m, enabling Los-MIMO implementation even in urban environments.

Figure 15 shows a possible implementation of a 4x4 Los-MIMO 100 Gbps capable solution. This “rendering” of the front side provides a realistic idea of the dimensions of such arrangements. In the same picture the most common parabolic reflector antennas (1 ft and 2 ft) are also shown for comparison (the D-band antenna is not to scale).

Figure 15. Comparing the size of traditional antennas with a 4x4 Los-MIMO 100 Gbps capable solution



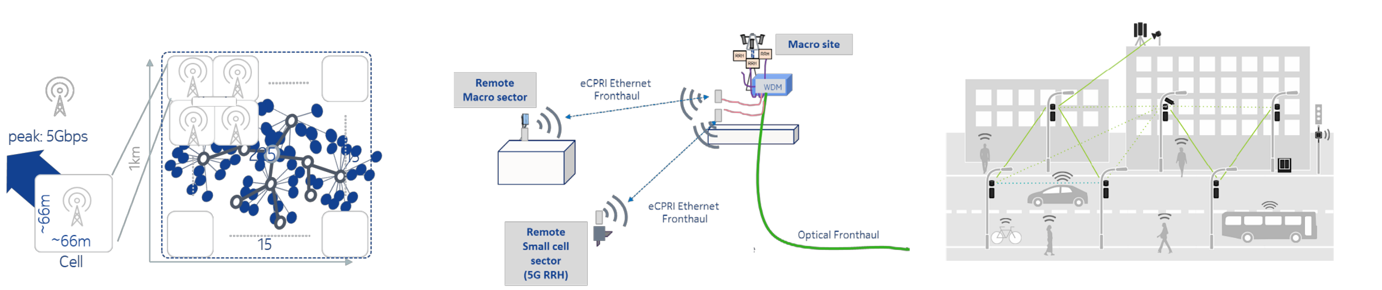
With these assumptions, i.e. very small dimensions and no critical restrictions for optimal antenna distance, it is not inconceivable that a single physical implementation with four transceivers could address most of the possible use cases in D-Band.

E-Band today and D-band in the future to bridge the connectivity “gaps” for 5G

Microwave technology that uses high frequency spectrum will cope with the connectivity challenges produced by the following use cases, as shown in figure 16:

- 5G millimeter wave access (i.e. 26-28-39 GHz): a significant number of new cell sites without proper fiber infrastructure are needed and CSPs are already considering wireless to complement fiber
- Remote RRH / small cells / massiveMIMO deployments: Point-to-Point (PtP) Ethernet fronthaul connectivity is needed to reach the macro cell or the first fiber point of presence (PoP)
- Small cells at street or rooftop level: here, small form factor, energy optimization, high resilience (e.g. by means of mesh topology through beam-steering) and rollout automation are the key elements.

Figure 16. The main 5G use cases can be addressed by millimeter wave technology



5G Millimeter-wave (26/28/39 GHz) Access
- Backhaul / F1
- PtP / PtMP / Mesh

Remote Macro-sector/small cells
- eCPRI
- Sub-6GHz RRH and Small cells

Small Cells low power deployment
- Backhaul / F1
- Sub-6GHz 4G/5G cells @street level

5G evolution network study, Megacity densification in Middle-East

Network densification and ten-fold higher throughput are major 5G challenges for CSPs. When fiber is not present, another option is to exploit the high channel bandwidth available in millimeter wave bands. Since rain is the main propagation impairment that affects connectivity performance at these frequencies, the trade-off between link distance and predicted outage must be carefully evaluated.

In this study, an existing 2G/3G/4G transport network in a dense urban environment of a tier 1 CSP was considered as illustrated in figure 17.

In the existing network, there is a high percentage of short and very short links, as shown in figure 18.

Figure 17. A study of a dense urban area served by a tier 1 CSP's transport network. The red dots represent the fiber PoPs

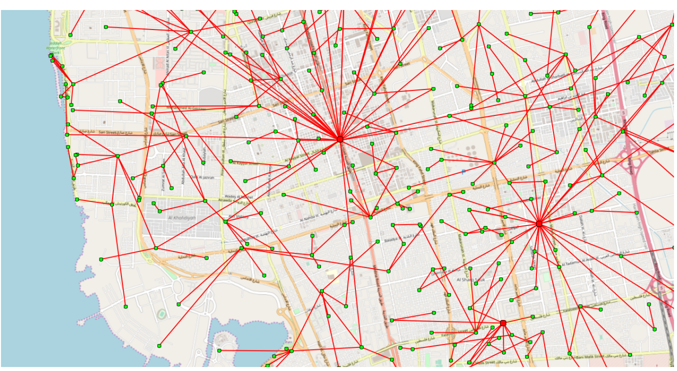
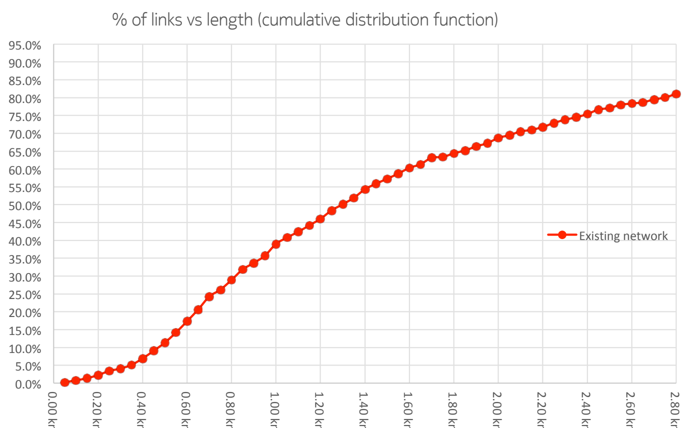


Figure 18. The study of the transport network shown in figure 17 reveals a high number of short and very short links



The following evolution scenarios have been analyzed with the aim of maintaining carrier-grade predicted performance:

- Adding a 5G layer on top of the existing site locations
- Densifying the RAN network by adding an additional 50 percent of new sites (with the assumption that these new sites cannot be served by new fiber)

The possible new microwave network is shown in figure 19 where the blue dots represent the new site locations (macro/small cells) served by new microwave links (blue lines).

Network densification reduces the average distance between adjacent sites as shown in figure 20. This condition will enable the possibility to deploy millimeter wave connections (i.e. E-Band/D-band).

Figure 19. A potential new transport network for the urban area shown in figure 17 but with a 5G layer and network densification. The blue dots represent new sites served by microwave links

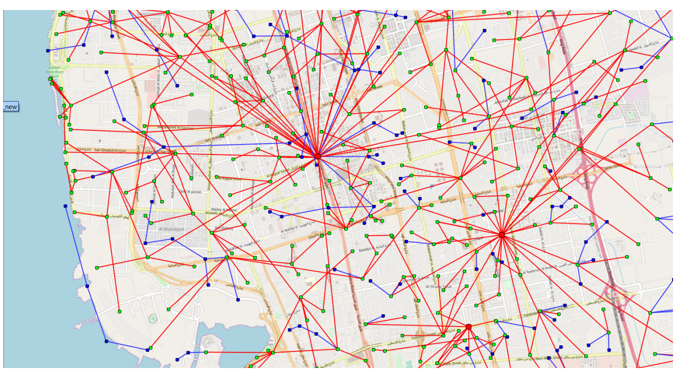
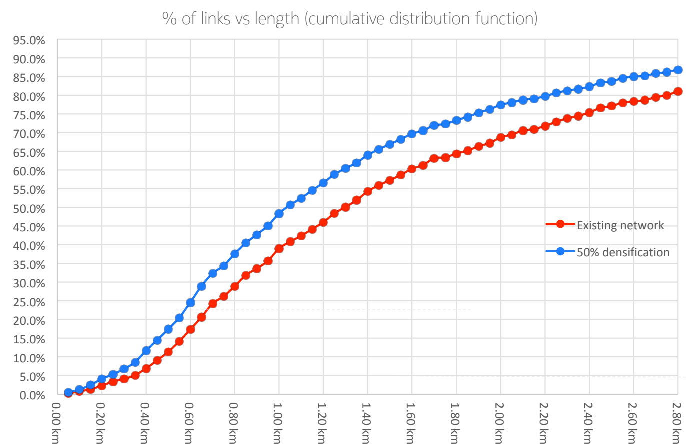


Figure 20. Densification of the transport network as shown in figure 19, shortens link length that may be served by millimeter wave connections



Similar results have been observed using data from deployed microwave networks in urban environments of different CSPs across the world. These studies confirm that 5G deployments in dense urban areas will likely enable millimeter wave technology as one of the preferred solutions for last mile “x-haul” connectivity. Moreover, fiber densification will shorten the distances between fiber PoPs and cell sites. Nokia estimates that in these scenarios, about 50 percent of new sites will be D-band ‘eligible’, hence offering carrier-grade performance.

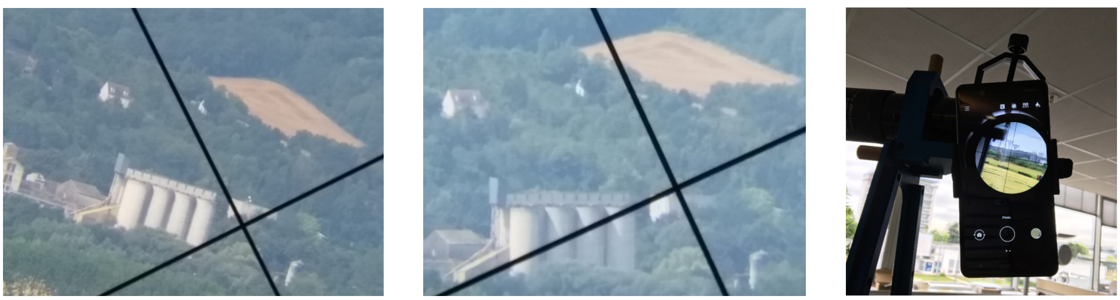
Carrier Aggregation and field test activities

Nokia has conducted carrier aggregation (E-Band plus traditional frequency band) trials with several tier 1 CSPs to prove the efficiency of this new technology. The carrier aggregation throughput of Nokia's microwave solution has been assessed through extensive measurement programs, with various configurations covering a full annual cycle (four seasons) in Europe.

To assure optimum antenna alignment, Nokia developed a special alignment kit to deal with long distance links and the narrow beam of E-Band (figure 21).

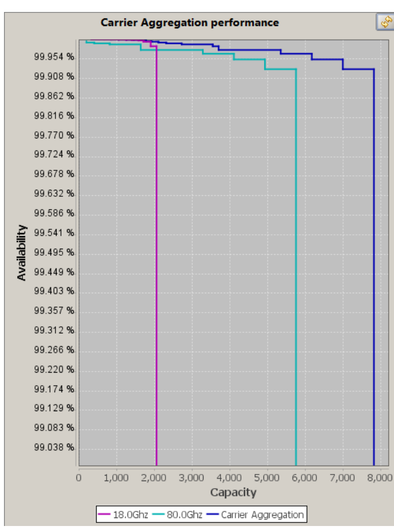
Figure 21. E-Band links have very narrow beams requiring precise alignment

<0.2^0 Perfect alignment



When carrier aggregation is adopted, traditional calculation methodologies are not sufficiently accurate to predict the system's behavior. For this reason, Nokia also designed an enhanced prediction tool for estimating the expected field performance as shown in figure 22.

Figure 22. Output of a Nokia-designed prediction tool estimating field performance

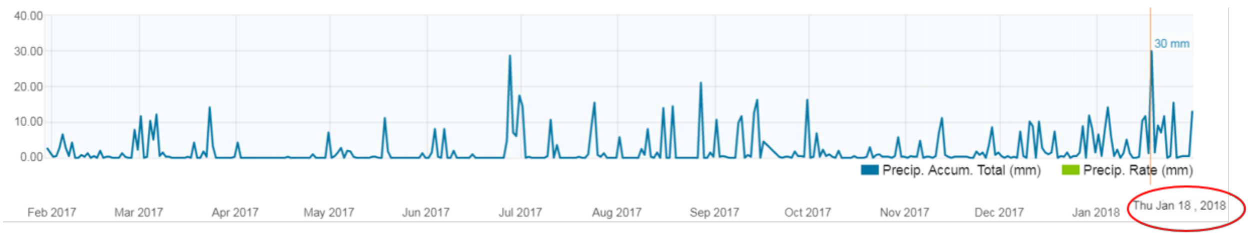


	18.0 GHz		80.0 GHz	
Modulation	Capacity	Availability	Capacity	Availability
4096QAM	2,063.8	99.983999%		
2048QAM	1,907.8	99.99487%		
1024QAM	1,717.5	99.99782%		
512QAM	1,580.5	99.998873%		
256QAM	1,406.9	99.999335%		
128QAM	1,255.7	99.99962%	5,756.2	99.930055%
64QAM	1,063.3	99.999792%	4,933.8	99.952989%
32QAM	850.8	99.999913%	4,111.4	99.966362%
16QAM	678.6	99.999978%	3,289	99.975266%
8PSK				
QPSK	339.3	99.999987%	1,644.2	99.988424%
BPSK			821.8	99.990925%
1/2 BPSK			410.9	99.992834%
1/4 BPSK			205.5	99.995637%

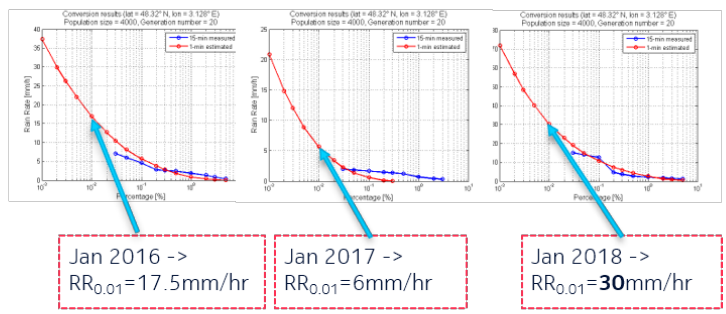
	18.0 GHz (dBm)		80.0 GHz (dBm)	
Modulation	TX power	RX signal	TX power	RX signal
4096QAM	19.2	-34.2		
2048QAM	19.7	-33.7		
1024QAM	20.2	-33.2		
512QAM	21.2	-32.2		
256QAM	21.2	-32.2		
128QAM	21.7	-31.7	13.5	-32.1
64QAM	21.7	-31.7	13.5	-32.1
32QAM	22.7	-30.7	14	-31.6
16QAM	22.7	-30.7	14	-31.6
8PSK				
QPSK	25.2	-28.2	16	-29.6
BPSK			16	-29.6
1/2 BPSK			16	-29.6
1/4 BPSK			16	-29.6

During a trial, Nokia experienced extremely heavy rain, totally atypical for the region, yet the overall field performance was in line with the predictions as shown in figure 23.

Figure 23. Despite heavy rain, unusual for the location at the time of a trial, predictions of actual perfromance proved remarkably accurate



January 2018 : rain intensity was totally atypical for the region



SDN-ready microwave achieves flexibility and automation in 5G networks

SDN is not disruptive, but an evolution of existing technologies, where applications are added based on the CSP's needs[9].

5G network evolution introduces new capabilities, but also brings high complexity which makes network automation a priority.

If managed in traditional ways, new complex networks would become expensive and error-prone operationally, increasing the time needed to respond to new network demands. CSPs would be forced to use valuable human resources in repetitive and sometimes impossible tasks, due to the large amount of information to be correlated to reach the right decisions[10].

CSP management systems and transport equipment must be able to sustain the evolution of future networks. A holistic approach, encompassing awareness of all network resources across domains and technologies, is needed to accomplish quick and flexible service instantiation and network optimization.

An SDN solution will meet the necessary requirements. The outcome will be an end-to-end transport and carrier solution across different technologies with a common management system. The path towards automation is built preserving existing investments and introducing new applications according to the evolving CSP strategy.

Automation and abstraction capabilities in the transport network are essential for dealing with dynamic service deployments, more challenging service requirements and limited network resources. CSPs will only need to define the mandatory end-to-end service requirements (e.g. end-points, interface parameters, bandwidth, latency, etc.) leaving the SDN controller to evaluate the best way to instantiate the services. Moreover, new sites can be seamlessly added to an existing network and immediately deliver the required services, based on their specific policies[11].

Monitoring and optimizing in real time

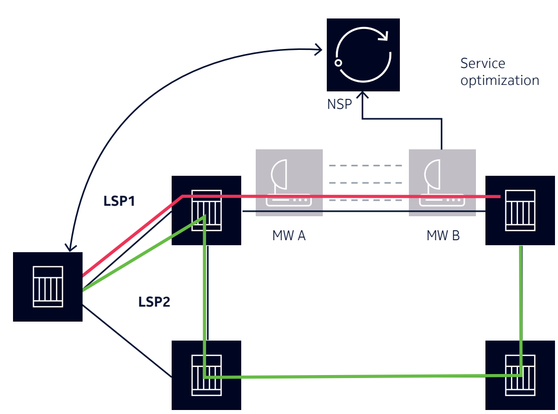
SDN also enables additional capabilities to monitor and optimize service performance in real-time, to check if they match the SLAs and initiate actions needed for best using available resources and highlighting possible network deficiencies.

From an architectural standpoint, the optimization framework requires three elements in the SDN controller:

- Network monitoring capabilities
- Optimization processes
- Capability to apply an optimization decision

One possible service optimization measure is traffic re-routing. Let's consider a service transported via a microwave network (see figure 24). Service and link performance are monitored in real time and, as soon as they stray outside expected values (e.g. if the radio link throughput decreases due to adaptive modulation change), the SDN controller evaluates the best path and automatically deploys a new configuration to steer the service away from the microwave branch.

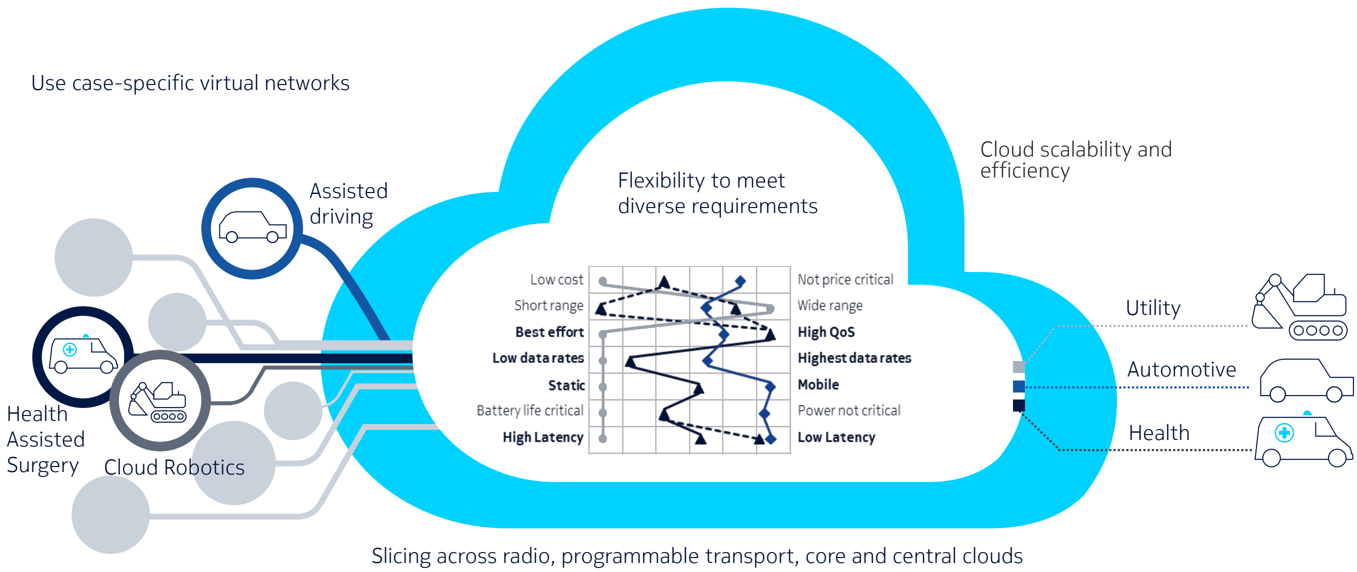
Figure 24. SDN-based service optimization with traffic re-routing



Resource allocation for network slicing

Network slicing architectures will be introduced with 5G. Network resources, both Virtual Network Functions (VNFs) and the transport network can be shared by different services. The network is virtually sliced in several, independent logical resources that can simultaneously accommodate multiple application fulfilment requests (see figure 25).

Figure 25. Network slicing in 5G enables the same infrastructure to fulfil many performance needs

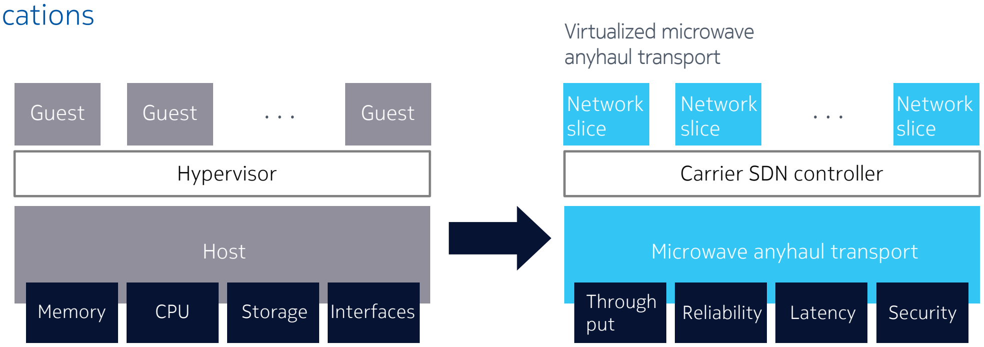


In a typical virtualized environment, the host provides hardware and software resources (memory, CPU, storage, interfaces) to one or more guests. These guests run applications independently and privately. A hypervisor arbitrates and enforces guests' resource requirements.

An SDN capable microwave network makes its resources available, including links with different throughput, latency, reliability and security capabilities, introducing a virtualized "anyhaul" transport service[12].

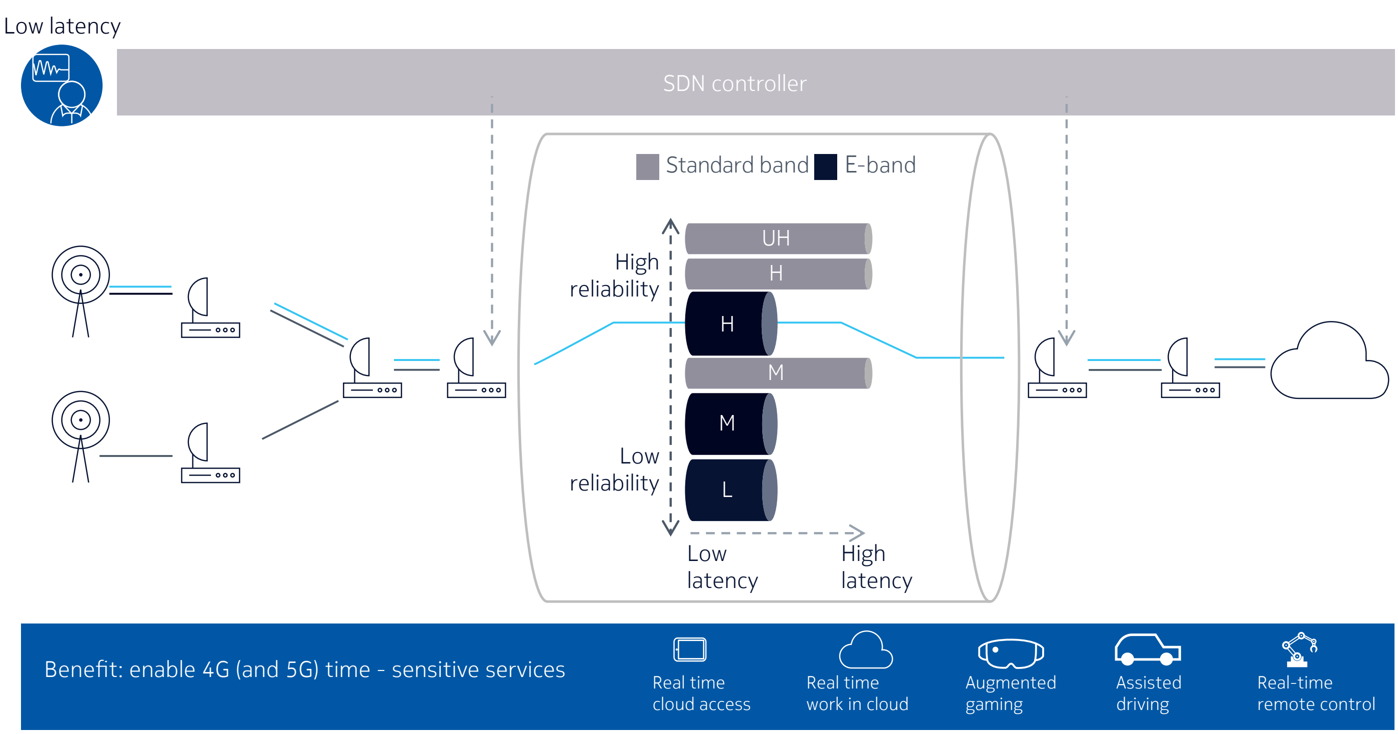
Network slices require several combinations of transport parameters based on the application they need to serve. The SDN controller acts as a hypervisor to allocate transport resources, properly leveraging service automation capabilities (e.g. instantiation of Layer 3 Virtual Private Network (L3VPN) services according to network slice requirements) as illustrated in figure 26.

Figure 26. Transport resources are allocated by the hypervisor to enable network slices to serve the required applications



Ultra-low latency applications, for example, could be served by a network slice allocating the service to the E-Band channel in carrier aggregation[13]. Other services not requiring low latency will be allocated by the SDN controller to the load balancing algorithm to efficiently exploit the carrier aggregation bandwidth (see figure 27).

Figure 27. The SDN controller allocates services for carrier aggregation to meet the needs of different applications



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Further benefits of SDN automation and optimization

Network slicing requires substantial service automation and optimization capabilities. Such a dynamic environment cannot be managed by humans due to network complexity and the required life-cycle speed of each service.

By carefully and dynamically tuning network resource utilization according to real-time needs, an SDN can also optimize the power consumption and significantly reduce TCO. Automation brings other cost optimization including advanced troubleshooting functions to reduce maintenance windows, smart analytics to identify critical situations and bottlenecks, and automated network release roll-out to reduce the software deployment life-cycle.

SDN controllers can enable a smart provisioning strategy. Site activation in an ultra-dense network would benefit from a Zero Touch Provisioning (ZTP) approach. With wireless transport technology, a pure ZTP approach would be limited to greenfield cases, to avoid the risk of losing the remote node reachability while configuring the radio link parameters of an existing network. Hence, a pure ZTP approach is not recommended and a hybrid approach, mixing pre-provisioning and centralized provisioning, can be taken. This involves automation tools to translate network design specifications into a system configuration file, prepared in the back office, that guarantees system reachability. The configuration file is then plug-and-play installed on site and, finally, the configuration is completed by the SDN controller.

The SDN network programmability principle opens the door to the implementation of several applications. The Nokia SDN architecture enables, for example, access to three possible cases:

- A set of turnkey solutions, leveraging applications embedded in the SDN controller distribution. These are designed by the vendor to guarantee their quality, maintenance, reliability and scalability
- Exploiting an automation framework, some use cases can be implemented with limited development efforts
- Building or integrating application from scratch relying on the SDN controller North-Bound Interface (NBI).

With Nokia SDN capabilities, CSPs will optimize the use of their network resources, reduce their TCO and minimize time to market and network outages.

Abbreviations

AI	Artificial Intelligence
CAPEX	Capital Expenditure
CSP	Communications Service Provider
fFDD	flexible Frequency Division Duplexer
FWA	Fixed Wireless Access
L3VPN	Layer 3 Virtual Private Network
Los-MIMO	Multiple Input Multiple Output in Line of Sight
NBI	North-Bound Interface
OPEX	Operational Expenditure
PoP	Point of Presence
PtP	Point-to-Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
SDN	Software-Defined Networking
SLA	Service Level Agreement
TCO	Total Cost of Ownership
TE	Traffic engineering
VNF	Virtual Network Function
XPIC	Cross Polar Interference Cancellation
ZTP	Zero Touch Provisioning

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