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5G SYSTEMS

ENABLING THE TRANSFORMATION OF INDUSTRY AND SOCIETY

A digital transformation is taking place in almost every industry, disrupting and making us rethink our ways of working. Through an unprecedented ability to share information, people and industries are collaborating more, creating solutions that combine many different areas of expertise and overturning traditional business models. This cross-industry transformation has created a need to evolve wireless connectivity for the fifth generation of mobile technology. The goal is to expand the broadband capability of mobile networks, and to provide specific capabilities for consumers and for various industries and society at large unleashing the potential of the Internet of Things.

INTRODUCTION

A digital transformation, enabled by mobility, cloud and broadband, is taking place in almost every industry, disrupting and making us rethink our ways of working. With the dawn of the 5G era, new use cases for the technology are emerging as consumers and enterprises set to work on identifying processes and channels that will boost the efficiency of their lives and their business. Wireless connectivity is at the center of this technological revolution. New business opportunities are opening up – both for those that have traditionally participated in the value chain, such as telecom operators, and for newcomers from other industries. Even the value chains themselves are undergoing a transformation, with content and end-to-end services becoming ever more important. New business models are being created with a focus on distributed cloud services and programmability of networks toward the edge. An unprecedented ability and willingness to share information is leading to a greater degree of collaboration between people and all kinds of different industries. Solutions that involve many areas of expertise are being created, overturning traditional business models and redefining ecosystems in the process.

This cross-industry transformation has created a need to evolve the concept of wireless connectivity for the fifth generation of mobile technology (5G), to enable new ways of defining performance monitoring and assurance as well as quality of service and level of user experience. Compared with previous generations of wireless communications technology, including 4G, the rationale for 5G development is to expand the broadband capability of mobile networks, and to provide specific capabilities not only for consumers but also for various industries and society at large, hence unleashing the potential of the Internet of Things (IoT).

A recent report by Ericsson [1] shows that "A small majority of European and North American operators believed 5G will be more consumer-driven, while a similar majority in Asia Pacific and Central and Latin America expected 5G to be more business-driven." A new survey report published by Ericsson [2] states that machine-to-machine (M2M) communications, broadband connectivity, cloud services, and mobile constitute a key driving force behind business innovation within the respondents' companies and industries. The great majority indicated they intend to make significant changes to their businesses in order to take maximum advantage of 5G when it arrives. Exploration of the corresponding business cases – in sectors such as agriculture, automotive, construction, energy, finance, health, manufacturing, media, retail and transport – is therefore critical to ensure that 5G standards ultimately meet the needs of the targeted customer base.

In this paper, the 5G use cases and their respective requirements are outlined first. The evolution of the network components toward 5G is then presented, followed by a description of the 5G system. Finally, the 5G system is exemplified through three concrete use cases.

5G FOR HUMANS AND MACHINES: USE CASES AND REQUIREMENTS

Several industry bodies have set the requirements in terms of what 5G actually is. Here we explore a number of promising use cases that represent various key sectors [3]: namely the automotive industry, construction, energy, health, manufacturing, media, retail and transport.

- Autonomous vehicle control enables an increase in autonomous driving, assisting humans, for instance, and bringing a number of benefits such as an improvement in traffic safety, increased productivity, improved quality of life and so on.
- Intelligent transportation systems (ITSs) facilitate efficient traffic management, dynamic traffic rerouting, traffic light control and so on.
- Emergency communication needs a reliable network that can help with the search and rescue of humans, and the identification and rectification of catastrophic problems involving machinery – even if parts of a network have been damaged in a disaster.
- Factory cell automation is a system including devices in an assembly line communicating with control units with a sufficiently high level of reliability and sufficiently low latency to be able to support critical applications. This may be associated with cloud robotics.
- Passengers traveling in a high-speed train are able to utilize the travel time for leisure or business activities while enjoying a user experience of the same quality as when they are either stationary or moving at a much slower speed.
- Large outdoor events held for a limited period in a defined area may be attended by a significant number of people. Such events include sports tournaments, exhibitions, concerts, festivals, fireworks displays and so on.
- A system that is able to communicate to and from massive numbers of geographically dispersed devices. Such a system can sense data, analyze it, make decisions, and control actuation – providing surveillance, for example, or implementing distributed feedback control and monitoring critical components, and so on.
- Media on demand supports an individual user's desire to be able to enjoy media content (such as audio and video) anytime and anywhere.
- Remote medical examination and surgery enables very low latency for telehaptic control so the surgeon gets tactile feedback that is designed to be indistinguishable from or better than manual operative techniques.
- Shopping malls can allow delivery of personalized shopping experiences.
- Smart city networks include remote monitoring of city infrastructure, real-time traffic information and public safety alerts for improved emergency response times.
- Stadium networks can offer audiences a blend of physical and virtual experiences during concerts and sporting events, and allow crowd sourcing through the sharing of personal points of view.
- Teleprotection in a smart grid network is the ability to react to rapid changes in the supply or usage of resources (such as electricity, water and gas) to avoid transient system failures that can damage equipment or cause customers the inconvenience of power outages.
- Traffic jam enables motorists or passengers to use travel time profitably for leisure or business activities, with the same level of experience they enjoy at home or at work.
- Virtual and augmented reality enable users to interact with one another as if they are in the same location. While virtual reality completely replaces a user's audio and visual sensory experience, augmented reality enriches it by providing additional information that is relevant to the surrounding environment.
- Broadband to the home bringing fixed wireless access (FWA) to a household by using cellular technologies the over last mile, while a router usually provides indoor access.

Even though 5G systems will have to address a wide range of use cases as illustrated above, in some of these, the requirements can be met by simply extending the 4G technical solutions already available.

Table 1 summarizes some of the most important requirements for each use case.
A detailed explanation of the requirements can be found in [3-7].

Use cases	Requirements	Desired value
Autonomous vehicle control	Latency	5ms
	Availability	99.999 percent
	Reliability	99.999 percent
Emergency communication	Availability	99.9 percent victim discovery rate
	Energy efficiency	One-week battery life
Factory cell automation	Latency	Down to below 1ms
	Reliability	Down to packet loss of less than 10^{-9}
High-speed train	Traffic density	Downlink (DL): 100Gbps/km^2, uplink (UL): 50 Gbps/km^2
	User throughput	DL: 50Mbps, UL: 25Mbps
	Mobility	500kmph
	Latency	10ms
Large outdoor event	User throughput	30Mbps
	Traffic density	900Gbps/km^2
	Connection density	Four devices/m^2
	Reliability	Outage probability < 1 percent
Massive numbers of geographically dispersed devices	Connection density	1,000,000 devices/km^2
	Availability	99.9 percent coverage
	Energy efficiency	10-year battery life
Media on demand	User throughput	15Mbps
	Latency	5s (start application), 200ms (after link interruptions)
	Connection density	4,000 devices/km^2
	Traffic density	60Gbps/km^2
	Availability	95 percent coverage
Remote surgery and examination	Latency	Down to 1ms
	Reliability	99.999 percent
Shopping mall	User throughput	DL: 300Mbps UL: 60Mbps
	Availability	95 percent for all applications, and 99 percent for safety-related applications
	Reliability	95 percent for all applications, and 99 percent for safety-related applications
Smart city	User throughput	DL: 300Mbps, UL: 60Mbps
	Traffic density	700Gbps/km^2
	Connection density	200,000 devices/km^2
Stadium	User throughput	0.3-20Mbps
	Traffic density	0.1-10Mbps/m^2
Teleprotection in smart grid network	Latency	8ms
	Reliability	99.999 percent
Traffic jam	Traffic density	480 Gbps/km^2
	User throughput	DL: 100Mbps, UL: 20Mbps
	Availability	95 percent
Virtual and augmented reality	User throughput	4-28Gbps
	Latency	< 7ms
Broadband to the home	Connection density	4,000 devices/km^2
	Traffic density	60Gbps/km^2

Table 1: The main requirements for the 5G use cases

5G SERVICES

The 5G use cases can be classified in terms of requirements for three essential types of communication with vastly different objectives: massive machine type communication (mMTC), critical MTC, and extreme or enhanced mobile broadband (eMBB). The three types that can be also designed as 5G services are discussed in the following.

Massive machine type communication

Otherwise known as Massive IoT, mMTC is designed to provide wide area coverage and deep penetration for hundreds of thousands of devices per square kilometer of coverage. An additional objective of mMTC is to provide ubiquitous connectivity with relatively low software and hardware complexity and low-energy operation. Many of the devices supported are battery powered or driven by alternative energy supplies, have small payloads, and might rarely be active, so they tend to be relatively delay tolerant for the most part. While the devices typically have a long lifespan, services and software need to scale and be swapped out relatively quickly to address new business opportunities. Examples that fall into this service category include the monitoring and automation of buildings and infrastructure, smart agriculture, logistics, tracking and fleet management.

Critical MTC or URLLC

The second category of application being addressed is that of cMTC, which is also called Critical IoT. In this type of application, monitoring and control occur in real time, E2E latency requirements are very low (at millisecond levels), and the need for reliability is great. The performance objectives of cMTC will be applied to workflows such as the automation of energy distribution in a smart grid, in industrial process control and sensor networking where there are stringent requirements in terms of reliability and low latency at the application layer. These are sometimes referred to as ultra-reliable low-latency communications (URLLC) requirements.

Careful attention will need to be paid to security in the case of both mMTC and cMTC. While higher network and device complexity is more readily acceptable in critical communication, mMTC will have to address cyber-security assurance with low-complexity devices. A hierarchical approach to the network is necessary to progressively improve security so end-to-end security assurance can be guaranteed.

Extreme mobile broadband

Providing both extreme high data-rate and low latency communications, extreme mobile broadband (eMBB) [3] also offers extreme coverage – well beyond that provided by 4G. Connectivity and bandwidth are more uniform over the coverage area, and performance degrades gradually as the number of users increases.

NETWORK EVOLUTION TOWARD THE 5G SYSTEM

The 5G system will imply major changes in the implementation and deployment of networking infrastructure, based on software-defined networking (SDN) and network functions virtualization (NFV). Network operations and services are becoming cloud-enabled in almost every industry, and the telecommunications industry is no exception – though it is distinct from other industries owing to the distributed nature of network operations. This creates an obvious opportunity to generate value from distributed storage and cloud computing towards specific clients and services as well.

The main domains of the 5G system are wireless access, transport, cloud, applications, and management including orchestration. We outline below how these will evolve towards a full-fledged 5G system (also exemplified in Figure 1).

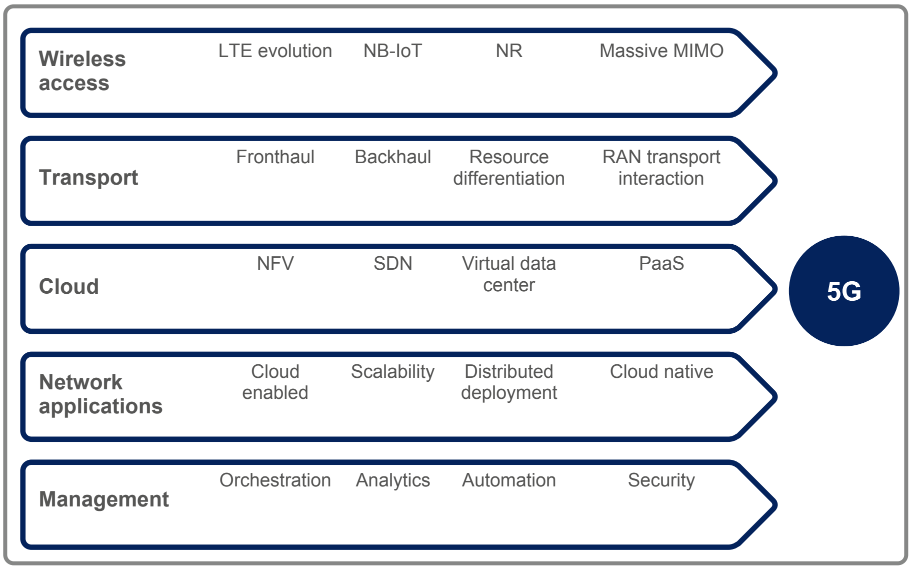

Figure 1: The 5G main components and their evolution

WIRELESS ACCESS

One key component of 5G radio access is an innovative air interface called New Radio (NR), which is designed primarily for new spectrum bands. In industry and academia it is generally understood that the success of 5G will depend on a diversity of spectrum assets which span low, medium and high spectrum bands. During discussions in WRC-15 [8] emphasis has generally been placed on high spectrum bands such as millimeter wave bands, although many administrations also realize that low bands below 6GHz will be key to providing the necessary coverage and bandwidth. LTE will of course continue to evolve, including advancements such as LTE-M and narrowband IoT (NB-IoT), and will be an important part of the overall 5G wireless access solution. Many administrations seem to equate 5G with bands above 24GHz. This is the case in the WRC-15 vision for IMT-2020, and for the FCC which has expressed an intent to release the 28GHz and 39GHz bands. NR is expected to migrate to bands below 6GHz in the near term, eventually occupying existing mobile bands below 3GHz.

A high level of interworking between LTE evolution and new radio access technologies is needed to ensure that 5G functionality can be introduced smoothly and over a long transition period. Such interworking will need to include support for dual-connectivity where, for example, a device maintains simultaneous connectivity to a dense high-frequency layer providing very high data rates as well as to an overlaid lower-frequency LTE layer that provides ubiquitous connectivity. User plane aggregation between LTE and any new radio technology such as NR is another example of this high level of interworking. It is important to note that even though new radio access technologies such as NR will require a new radio bearer, NR and LTE will be fully integrated from a system perspective so NR can both be added as a stand-alone system – for industry applications, for example – or as a natural evolution of the existing wide area LTE networks.

Additional key technology components for the 5G radio access solution include:

- advanced multi-antenna technologies such as massive MIMO and beamforming with phased antenna arrays
- ultra-lean transmission to reduce interference caused by common signaling resources and to maximize resource efficiency
- flexible duplex in certain isolated local network deployments
- access/backhaul integration, where access and (wireless) backhaul share the same technology and the same overall spectrum pool
- well-integrated device-to-device communication.

These technology components will not only apply to the new technology part of the 5G wireless access systems but also, to a large extent, to the evolution of LTE.

TRANSPORT

The transport domain delivers connectivity between remote sites and equipment/devices. Backhaul serves both ends of the transmission – for example, to connect a base station (BS) to an access network or a central office – while fronthaul is a term used when the BS antennas are connected to a remote integrated radio frequency (RF) unit, or to a centrally located baseband (BB) unit. In addition to providing bulk connectivity for the operator's mobile network fronthaul and backhaul, the transport domain may offer different types of customer facing connectivity services, such as a Layer 2 or Layer 3 VPN.

5G RAN technology puts new requirements on the bandwidth and latency of transport networks. Consequently, a high degree of automation and coordination within and cross network domains will be required. A concept known as RAN transport interaction (RTI) introduces coordination between the radio, transport and packet core layers of an operator's mobile network, providing network-wide optimization and service assurance. Examples of such coordination include:

- support for various industries extending network resource differentiation into the transport network
- proactive congestion management, enabling transport aware RAN load balancing for improved user QoE
- securing fairness between radio technologies within the transport network.

CLOUD

Network functions (as well as other types of applications) in 5G will increasingly be deployed as virtualized software instances running in data centers. This pattern of deployment, which has been characterized as cloud deployed SDN/NFV, simplifies scaling and management of network infrastructure such as deep packet inspection engines and firewalls. SDN is about the separation of the network control traffic (control plane) and the user specific traffic (data plane). SDN is based on the centralization of configuration and control, while ensuring a simple data plane architecture. NFV is about virtualizing network functions (by implementing them in software) and the functions that can run on a range of standard hardware.

The cloud allows infrastructure to scale in or out and automatically; in other words, when an application needs more resources, the cloud automatically spins up another instance of that application, and removes an instance when load decreases. Such flexible scaling is impossible to achieve when the application is implemented with dedicated hardware. Data security in a virtualized cloud environment will ensure that only authorized access is allowed to the infrastructure application's data store. In addition to this, the infrastructure application may be deployed in a virtual data center (DC) that is distributed between many physical data centers. A VDC is a collection of virtual machines, virtual network connectivity and associated storage that regards the infrastructure applications as a data center. One way to simplify provisioning and control of an application across a VDC will be to define a network slice as a virtual network and let the owner of the slice manage it themselves, within constraints placed by the network provider.

The cloud will offer an increasing number of comprehensive platforms as a service (PaaS) to make it easy to develop new applications.

NETWORK APPLICATIONS

Network applications such as Evolved Packet Core (EPC), voice over LTE (VoLTE), and future 5G core network functions will be cloud enabled: that is, they will have the ability to execute in the SDN/NFV cloud environment. Consequently, the applications will have the advantage of being automatically scalable as well as flexible in terms of where in the network they can be deployed (centrally, distributed or a combination of the two).

For example, the complete core network can be deployed in a local server in a factory to support exceptionally short response times. At the same time, it should be possible to support the factory with communication services from a centrally placed VoLTE installation, for example.

Another example is the case of media distribution, where the media delivery may be optimized for bandwidth, latency and cost by deploying a content distribution network very close to the edge. In this way, customers can experience virtual reality and augmented reality productions within latency and bandwidth constraints.

New applications are increasingly designed to be cloud native. Instead of designing applications with integral aspects and functions, applications rather use services offered by the cloud PaaS.

MANAGEMENT

Network management of entities in 5G systems will be able to automate and orchestrate a range of lifecycle management processes, and will be capable of coordinating complex dynamic systems of applications, cloud, transport and access resources.

Network management in 5G systems requires additional work to include VNFs deployed in cloud data centers. In cloud-deployed systems, orchestration is needed to arrange and coordinate automated tasks and allocated resources through centralized management. The result is a workflow to provide the desired network behavior. Management entities evolve from ordering explicit configurations (configuring a router or a server, for example) to distributing policies, KPIs and target goals that each subsystem optimizes autonomously and locally.

Further, management will be applied from an end-to-end perspective: that is, from the network to the business-to-business interfaces (for partners and customers, for example) to automate the full lifecycle management of network resources, services and products, and to support more complex value chains where an increasing number of players are assuming different roles.

Finally, it should be noted that analysis and security are essential functions that can be considered part of 5G network management.

Analytics is a key tool for increasing automation of operations by providing prediction insights that can be applied automatically.

Security and privacy in 5G networks will be characterized by new trust and service delivery models, an evolved threat landscape, and increased privacy concerns. In particular, 5G networks will have to manage the following key pillars: security assurance, identity management, radio network security, flexible and scalable security architecture, energy efficient security and cloud security.

THE 5G SYSTEM

The 5G system, which is shown in Figure 2, will be built on "flexible" radio access nodes, distributed and centralized data centers allowing for flexible allocation of workloads. These nodes and data centers are connected via programmable transport networks. The transport networks are connected via backbone nodes that carry the information from the access nodes to the data centers where most of the data is stored and the network is managed. Figure 2 illustrates that all applications, including many network applications, are run on top of a cloud with exception of dedicated functions in the access nodes. The applications can be centralized (App 3 and App 4) or distributed (App 1, App 2), depending on the requirements.

In addition to this, the management of applications, cloud, transport and access resources are shown centrally in the data center but can of course also be flexibly allocated as necessary.

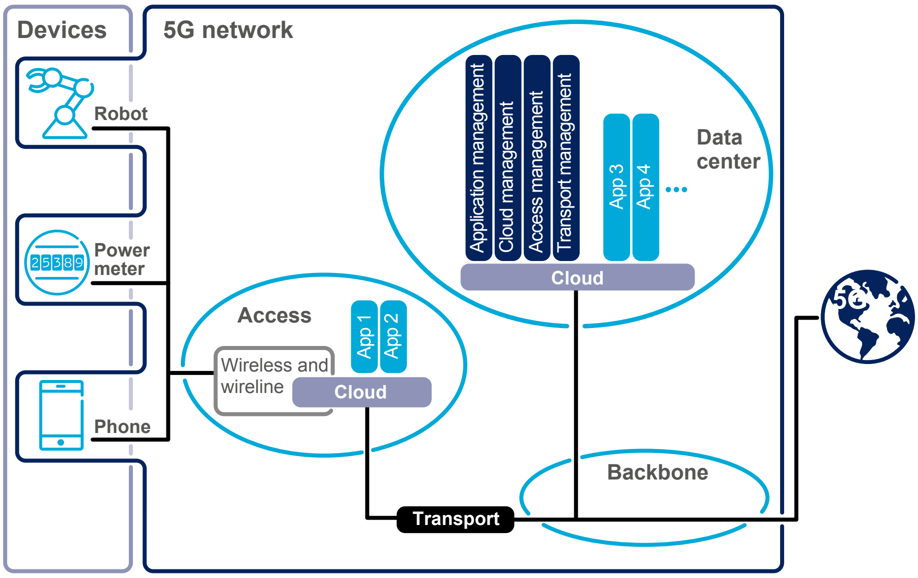

Figure 2: The 5G system

The 5G system will fully support the concept of network programmability for all types of services. A service can be flexibly allocated anywhere in the network, at a network node, end-user device or external host. A service may not be confined to an operator's network, and may originate from outside the network domain.

E2E orchestration is needed to match external business offerings with network efficiency. For example, to optimize content delivery in eMBB service, orchestration would place virtualized network functions on resources that are physically close to the subscriber.

NETWORK SLICING

The technique of network slicing allows for the definition of multiple logical networks (or slices) on top of the same physical infrastructure. Resources can be dedicated exclusively to a single slice or shared between different slices. There are different types of resources such as computing, storage, access equipment, transport, VNFs, and so on.

A network slice is built to address a desired behavior from the network. Such behavior can be associated with security, data-flow isolation, quality of service, reliability, independent charging and so on. A network slice may support one or many services, and can be used to create a virtual operator network and may provide customized service characteristics. Network slicing can be used for several purposes: a complete private network, a copy of a public network to test a new service, or a dedicated network for a specific service.

For instance, when setting up a private network in the form of a network slice that can be an end-to-end virtually isolated part of the public network, the network exposes a set of capabilities in terms of bandwidth, latency, availability and so on. Thereafter, a newly created slice can be locally managed by the slice owner who will perceive the network slice as his or her own network complete with transport nodes, processing and storage. The resources allocated to a slice can be a mix of centrally located and distributed resources. The slice owner can initiate applications from his or her management center, and applications will simply execute and store data, either centrally, in a distributed management system or a combination of both.

AN EXAMPLE OF A 5G SYSTEM: AN ARCHITECTURE THAT CAN BE ADAPTED TO SERVICES

The support for the wide range of 5G services will dictate a flexible 5G architecture for the access and core networks. In particular, a software-configurable purpose built architecture [9], [10] and [11] with flexible deployment alternatives will be needed to provide the required overall cost efficiency.

To illustrate the flexibility of the 5G system architecture, the realization of three use cases will be considered, each corresponding to a different 5G service. The first, massive numbers of geographically dispersed devices, requires the mMTC (Massive IoT) service. The second is virtual reality, and will use the 5G eMBB service. The third is factory automation, and this is realized by the cMTC (Critical IoT) service. The deployment architecture corresponding to these cases is shown in Figure 3, realized here by separate network slices supporting each service. Network slicing provides multiple benefits including the possibility to optimize the functional deployment and the network function configuration. It is also beneficial for independent operations and lifecycle management of each network slice.

In the following, we will explain the main architectural components of each case. It is important to note that several intermediate nodes (at regional sites, for example) may exist between the access and the primary data center site, but they have been omitted for the sake of simplicity. Further, the radio access technology functionality is divided between the antenna location (RF part) and BS site (BB part), representing the split architecture in 5G RAN [11].

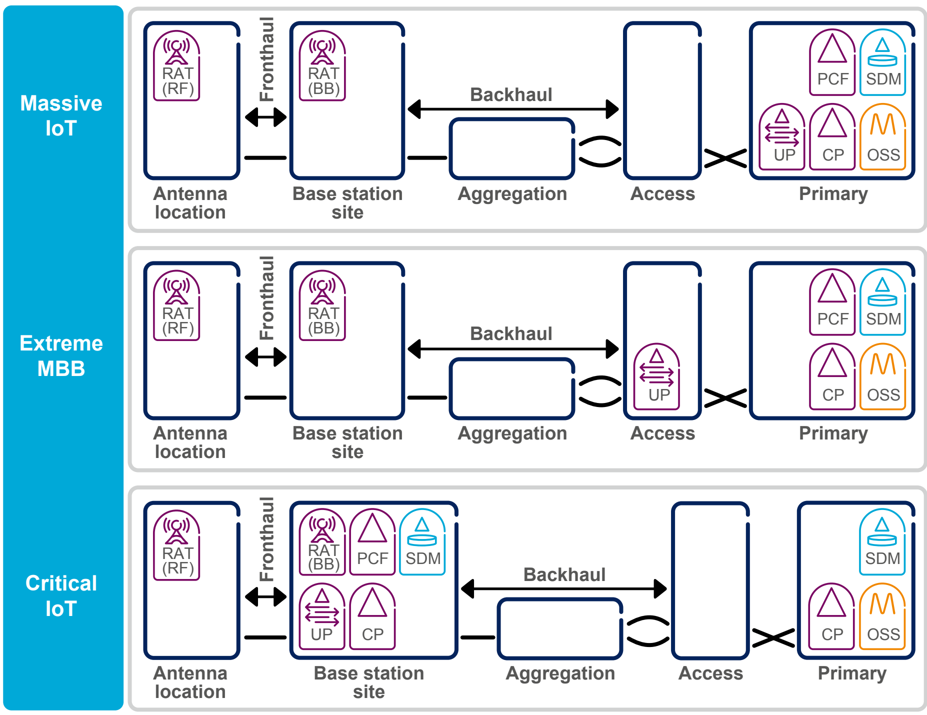

Figure 3: The 5G adaptable architecture

MASSIVE NUMBER OF GEOGRAPHICALLY DISPERSED DEVICES

A generic use case, the massive number of geographically dispersed devices falls under the mMTC service. It may be a question of devices connected to parking meters in a city, or asset tracking in an industrial site, for example. Most of these devices are characterized by low cost/complexity (half duplex, low power, single antenna), long battery life (more than 10 years) and have significantly improved coverage (a 15-20dB better link margin than LTE). They are mostly static and largely generate traffic on the uplink. Recently, NB-IoT was finalized by the 3GPP in 2016, and it addresses most of these requirements.

The basic architecture for mMTC looks simple. The main challenges arise from the very large number of devices to be supported, leading to a substantial increase in the control signaling relative to the user plane traffic. In addition, the mobility tracking can further increase the burden on the network.

From the top of Figure 3, it can be seen that the radio access is executed at the base station close to the devices, while the other main functional components such as the control plane (CP) that also includes the mobility management, subscriber data management (SDM), and the user plane (UP) are conducted in the central primary site. From a business perspective, it is recommended that mMTC is separated from the eMBB network instance in order to simplify the subscription management and Business Support System (BSS) due to different business and go-to-market models.

The main technology techniques required to provide an mMTC service are Extended DRX (to extend the battery life), time repetition (to improve the coverage), enterprise managed devices (identity management outside the network/operator control), and E2E security for payload data.

VIRTUAL AND AUGMENTED REALITY (FROM AN ENTERTAINMENT PERSPECTIVE)

The high data capacity and low latency requirements of virtual reality will require a separation of the control and user data plane where the user plane is being distributed closer to the user (for example, the UP is placed in the access site while the CP is kept in the primary data center), as illustrated in the middle of Figure 3. This will allow to optimize the access to applications in terms of capacity and latency, assuming service applications are distributed as well. The other functions such as SDM, operations support systems (OSS) and policy control function (PCF) will be executed in the primary data center.

The main characteristics of eMBB such as high data capacity can be achieved, for example, using advanced multi-antenna technologies (MIMO and beamforming) as well as distribution of the optimized UP of the core network.

FACTORY AUTOMATION

The factory automation use case requires cMTC services. The most stringent requirements are very low latency and high reliability since jitter is not tolerated for precise operation such as the cell automation in a factory. In practical terms, one of the most significant challenges will be to support cMTC business services where high-grade network slices need to provide the required levels of availability, robustness and resilience to attacks.

The ultra-low latency for the cMTC service will have implications for the 5G architecture functions. In particular, there will be a need to:

- push application processing to the mobile edge
- or potentially have local deployment – for example, local break-out in the factory where parts of the core network such as the PCF, UP, CP and SDM are placed or duplicated to support standalone system operation
- provide a robust radio perimeter security.

An example of the high-level architecture of the cMTC service is shown at the bottom of Figure 3, where the UP and CP have been placed on the BS site along with a "duplication" of some the core functions such the PCF and SDM.

The main technology components that allow the low latency and high reliability requirements to be met are high frequency or space diversity, a very short transmission timeframe, and distributed processing. Further, with regard to security, non-SIM-based authentication (AAA) and enterprise managed devices (identity management outside the network or beyond the operator's control) are envisaged.

CONCLUSION

With connectivity at the heart of industry transformation, 5G systems have a significant role to play – not just in the evolution of communication but in the evolution of businesses and society as a whole. 5G will build on and extend the public network, making it viable for any type of applications. Consequently, 5G will be the major enabler of the Internet of Things and the Networked Society.

As a natural evolution of current network architecture, broken up into building blocks through access, transport, cloud (including SDN and NFV), network applications and management (including orchestration and automation), 5G systems will provide a higher level of abstraction that will simplify the management. The 5G architecture will not only be cost-efficient to operate, it will have the agile and flexible mechanisms in place for the swift introduction of services. These properties are required to enable new business models that can rapidly generate new revenue opportunities. For that reason, 5G systems will be built in the form of programmable platforms that provide functionality on an “as-a-service” basis. Network slices are key to delivering differentiated offerings, as they can provide a complete solution environment that is adapted for specific application usage – and they do this in a way that uses network resources efficiently.

The 5G transformation has already started with NB-IoT, NFV and management automation, for example. It is an incremental process, enhancing the current network in a step-by-step fashion. As the process unfolds, global partnerships will prove essential to enabling a cross-industry engagement in defining and building the 5G system.

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GLOSSARY

AAA	authentication, authorization and accounting
BB	baseband
BS	base station
BSS	Business Support System
CP	control plane
DC	data center
DL	downlink
E2E	end-to-end
eMBB	extreme or enhanced mobile broadband
EPC	Evolved Packet Core
FCC	US Federal Communications Commission
FWA	fixed wireless access
IoT	Internet of Things
ITS	intelligent transportation system
M2M	machine-to-machine
MIMO	multiple-input, multiple-output
mMTC	massive machine-type communication
MTC	machine-type communication
NB-IoT	narrowband-IoT
NFV	Network Functions Virtualization
NR	New Radio
OSS	operations support systems
PaaS	platform as a service
PCF	policy control function
RAN	radio access network
RF	radio frequency
RTI	RAN transport interaction
SDM	subscriber data management
SDN	software-defined networking
VNF	virtual network function
UL	uplink
URLLC	ultra-reliable low-latency communications
UP	user plane
VDC	virtual data center
WRC	World Radiocommunication Conference