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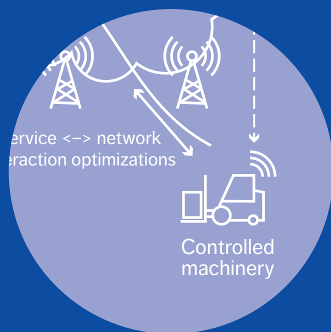
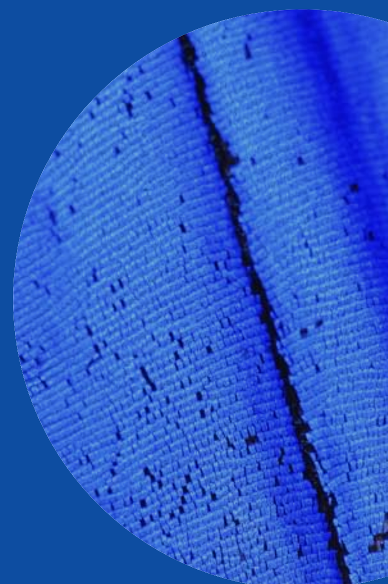
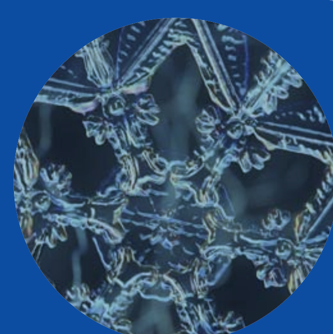




INDUSTRIAL REMOTE OPERATION: 5G RISES TO THE CHALLENGE



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INDUSTRIAL REMOTE OPERATION

5G rises to the challenge

Ericsson and ABB are collaborating to determine how to make the most of 5G and cellular technologies in an industrial setting. We are looking at a number of use cases, each with its own challenging set of connectivity requirements. This article presents some of the use cases being assessed, highlights the challenges posed by remote operations, and describes how 5G technology can be applied to overcome them.

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Use cases, benefits, and drivers

Power plants, mines, construction sites, and oil platforms can be hazardous environments. Industrial sites like these can be noisy and dirty, and may expose personnel to an abundance of risks associated with falling objects, harsh weather conditions, and the presence of heavy machinery and chemicals.

Business incentives like reducing the risks associated with working on remote sites have led industrial players to consider ways of minimizing the numbers of operational personnel needed. Deploying a remote- or teleoperation for heavy machinery and other equipment is one way to cut the size of the on-site workforce. Remote operation solutions allow people to operate machinery from the safety of a control center at another site – sometimes even several hundred kilometers away.

With the right system design, remote operation enables an increased level of safety, and in some cases leads to more efficient use of resources. For example, operators can run a number of machines at several different sites from the comfort of a centralized control center. Control centers can in turn be established in strategic locations; it tends to be easier to attract experts to an urban area than a remote location. Running a remote operation can also help to reduce the high cost of building the kind of infrastructure often associated with sites that are isolated. However, at times, remote operators may not be as productive as on-site manual operators owing to their reduced sense of a machine's surroundings. Operating a wheel loader in a mine on a remote basis, for example, is less efficient than handling it manually on-site, as it is harder to fill the loading shovel with as much material.

Productivity can, on the other hand, be improved by including a certain degree of automation in the solution – to help the operator with the most challenging tasks. Repetitive tasks can be almost fully automated, with operator intervention reserved for handling unexpected events, such as when an object is dropped or something gets broken. For other jobs that may be carried out more effectively by a machine than a human being – such as precise linear movements and constant contact force control – an automatic controller may be used to assist the operator. In the case of a remotely operated robotic arm, the robot and the operator can have joint control, depending on the degree of freedom and motion required.

The possible use cases for remote operations in industry are numerous, and each scenario brings its unique set of challenges.

Mining

The modern mine is crowded with vehicles and machines performing a variety of tasks, both on the surface and underground: trucks, drills, trains, wheel loaders, and robots designed for specific tasks are all typical examples. Mines are high-risk environments, and the ability to move people and equipment from one place to another is key, given that certain areas can take a considerable amount of time to reach.

The ability to move driverless equipment into place quickly, say following a blast, is a potential time-saver when people are not permitted into the area until fumes have cleared. Benefits like this, combined with the fact that mines are typically found in remote locations, have led the mining industry to become an early adopter and developer of remote machine operation.

Construction sites

The incentives for the construction industry to implement remote operations are similar to those that apply in mining. In both industries, heavy machinery is required, such as excavators, wheel loaders, compactors, and haulers – all of which can be worked remotely to advantage. Unlike mining, machinery used in the construction industry moves from one site to the next, which requires a more flexible operating solution that can function without the need for fixed on-site infrastructure.

Ericsson's research addressing remote operations for the construction application was demonstrated

Terms and abbreviations

3GPP–3rd Generation Partnership Project | DECOR–dedicated core network | E2E–end-to-end | FEC–forward error correction | IP–Internet Protocol | IR–infrared | LTE–Long-Term Evolution | MWC–Mobile World Congress | NFV–Network Functions Virtualization | NX–Ericsson's 5G air interface initiative | RAN–radio-access network | RTP–Real-time Transport Protocol | SCTP–Stream Control Transmission Protocol | SDN–software-defined networking | SLA–Service Level Agreement | SRTP–Secure RTP | TTI–Transmission Time Interval | UDP–User Datagram Protocol | UE–User Equipment

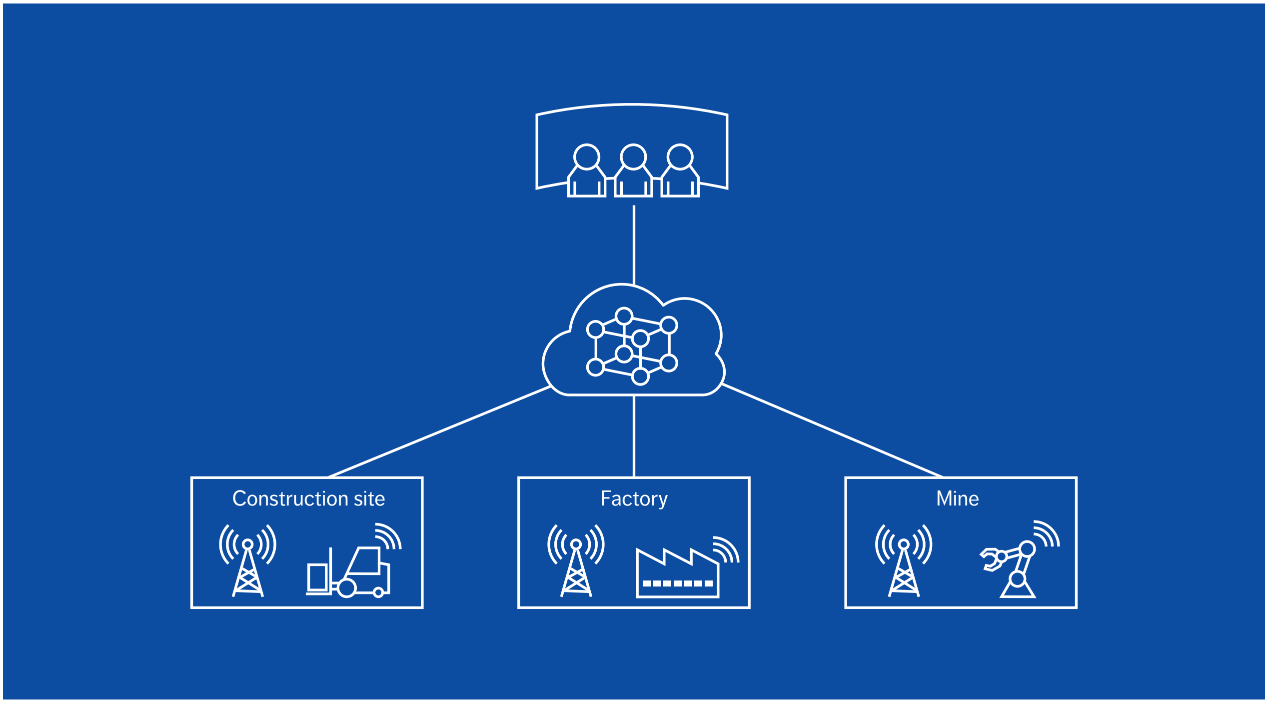

Figure 1:
Remote operation of machines

Figure 2:
Remote mining control center (Garpenberg, Sweden)
Photographer: Hans Nordlander

at MWC in 2015 [1]. The trials leading up to the demo aimed to determine the network requirements like latency and throughput, as well as the performance needs for the audio and video equipment – with a view to ensuring that 5G will meet the specifications.

Harbors

Large cargo ships can carry over 16,000 containers. Loading and unloading is a time-consuming process often requiring a number of cranes working simultaneously for many hours at a time. Traditionally, each operator sits on-site in the control cabin of the crane, high above ground. Cranes need to be operated with speed, precision, and consistency. With smart cranes and remote operation, safety and productivity levels can be increased, while operator stress levels can be reduced. The comfort of the control room offers many benefits in terms of wellbeing, as it:

- saves the time spent accessing a crane's control cabin
- provides a favorable job environment with improved ergonomics
- reduces exposure to adverse weather conditions
- improves the security and safety of personnel

ABB has developed a solution to remotely operate cranes from a control room in the harbor, where the operator's work is facilitated by a video feed from the crane [2]. Centralization is the natural next step in the development of this solution, enabling multiple cranes situated at different sites to be operated from the same station.

Surveying and inspection

Drones, robots, and vehicles that are remotely operated are suitable for applications like land and sea inspection, where the safety issues arising from the distances covered, adverse weather conditions, and hazardous terrain can be costly to address. Remote operations work well for these types of monitoring applications, and are ideal for observing industrial and construction sites in out-of-the-way places, or large indoor venues and warehouse environments.

Video streams and other sensor data are fed back to the operator, enabling appropriate action to be

Figure 3:
Remote operation station
Photographer: Hans Nordlander

Figure 4:
Harborside cranes for loading and unloading cargo
Photographer: Hans Nordlander

taken. By combining remote inspection with remote manipulation, the level of automation can be raised. For example, a remotely operated robot in a data center can rapidly swap out a malfunctioning server, or respond to other types of hardware failures [3].

Oil and gas
The oil and gas industry operates in environments that are harsh – both for people and equipment. Inspection, servicing, and operation of equipment as well as monitoring of leaks are just some of the routine applications. Remote operation is highly applicable to this industry, but to fully reap the potential benefits, equipment must remain functional without the need for regular on-site maintenance. One of the main benefits of remote operation is a reduction in the need for people to work in hostile environments, and frequent maintenance visits would negate this benefit [4].

Remote surgery
The use of teleoperation technology is emerging in the field of medicine. It enables surgeons to perform critical specialized medical procedures remotely – allowing their vital expertise to be applied globally. While this application area is still in its infancy, it is likely to become more widespread as the technology becomes more advanced.

Challenges
For remote operation solutions to function effectively, sensory information like sounds and images needs to be transferred to the teleoperator from the equipment being controlled and its surroundings. Ensuring that audio and visual feeds are sent with minimal distortion enables the teleoperator to gain a good understanding of the remote environment, which leads to improved productivity and safety.

Remote operations would become even more efficient and intuitive if sensory data additional to the basic audio and visual information were included in the solution. Just as manual operations rely heavily on the human ability to balance and touch things, remote operation applications – whether industrial, medical, or recreational – can benefit greatly from the incorporation of this type of sensory information. The addition of touch and balance to the operator feed can be achieved by the use of haptic interaction and force feedback. The ability for the operator to actually feel the vibrations when an object like an excavator bucket hits the ground, or to sense when a robot arm touches its target is highly valuable in terms of productivity, cost, and safety.

Additional sensors and technologies, like gyros, accelerometers, radars, lasers, lidars, and thermal and IR sensors can be used to gain more information from the remote site and provide enhanced control at the operator end.

The negative effects of bad media quality, or an imperfect representation of the remote equipment and its surrounding environment, can be alleviated to some degree through training. Before full productivity can be achieved, operators require training and experience of operating equipment remotely – even if they have previously operated the same or similar equipment on-site.

Remote operation isn't a one-size-fits-all solution. Owing to the range of equipment and the many potential scenarios in which remote applications apply, the array of use cases that could benefit from remote operation is extensive. An extra level of variation arises from the need to weave environmental parameters – such as rain, snow, dust, dirt, vibrations, and visibility – into system design. For example, remotely operating a dumper that moves cargo loads in and out of a mine is fundamentally different from performing surgery using a remote-controlled precision robot. But even less obviously contrasting examples, like operating a dumper in differing visibility conditions, can present significant challenges for the technical solution.

Communication requirements
Securing a high-quality communication link between the control station and the machines being operated is key to accurate and effective remote operation. Existing solutions tend to use cable or Wi-Fi to implement the last hop of this link. Cable provides low latency and high reliability, but it is costly to install and modify – which is significant when machines are constantly being moved from

one site to another, such as in the construction industry. WI-FI is a low-cost alternative that provides a certain degree of mobility – within the coverage area of the WI-FI network. Both solutions require dedicated on-site installation and a connection to the control center over the public internet or through a leased fixed-line connection.

To provide remote operation solutions with connectivity, standardized cellular systems offer a number of benefits over wired connections or WI-FI. First, using an operator-managed cellular network eliminates the need to install on-site infrastructure. Second, cellular offers widespread coverage and mobility solutions that can provide connectivity to mobile machinery and devices. Furthermore, as they use licensed frequency bands, cellular links are highly reliable, and the required level of security can be guaranteed. However, the requirements set by some use cases, which are of interest to society and certain industries, cannot easily be met by existing communication technologies.

A simple, quick and flexible on-site installation process is a basic requirement for many remote operation applications. Machines might be portable or driverless and may be required at different locations during the same working day. Job sites can be temporary and may grow, and their communication needs may change over time – which tends to be the case in construction and mining. For such environments, wireless solutions are preferable as they offer the desired level of flexibility and ease of installation, they can support equipment that is on the move, and do not require any cables.

For the most part, industrial companies expect global communications to be delivered with E2E Service Level Agreements (SLAs), which they can handle themselves to some degree. Providing E2E SLAs, however, presents a challenge given that the system may span multiple public operator networks and even infrastructure owned by the enterprise itself.

High-definition video is a fundamental element of remote operation solutions. To deliver heavy video streams requires connection links with high minimum bitrates, especially when applications require high-resolution images, fast frame rates, stereoscopic video, immersive video, or multiple viewpoints (several camera feeds). Low media quality severely degrades the user experience, which inevitably leads to a drop in productivity. The exact bandwidth requirements are, however, highly dependent on the use case.

> “REMOTE OPERATION ISN'T A ONE-SIZE-FITS-ALL SOLUTION”

Like most real-time applications, remote operation requires connection links with low latency and low jitter characteristics. To operate equipment (like an excavator or a robot) efficiently on a remote basis, the time lapse between the instant an operator sends a control instruction to the moment the equipment's reaction is sensed by the operator must be as short as possible.

The toughest latency requirements occur in applications that include haptic interaction. A typical haptic control loop in a remote operation application requires latency to be below 10ms [5], and in some cases, the round trip time should not exceed a couple of milliseconds. To put this figure into perspective, current LTE networks have an average latency of 30ms, which in some cases can rise to 100ms or more if packets are delayed.

Some degree of toleration to packet loss in remote operation applications is expected. However, packet loss may result in lost or delayed control commands, which can cause machinery to stop, can be costly, and can cause damage to equipment or even injury to personnel. So, to guarantee the continuous and safe operation of machinery, the communication link and the entire solution need to be highly reliable.

System outages or hijacked equipment resulting from a cyber-attack or other security intrusion can have severe consequences. Personnel safety is jeopardized, business continuity can be affected, and expensive equipment may be damaged. So, security is a key consideration when designing any remote operation system.

Proper audio and video feed synchronization is critical to provide the operator with a clear understanding of what is happening at the remote location. The synchronization requirements for remote operation solutions that incorporate haptic interaction and force feedback are much stronger than for a videoconference, for example. Without proper synchronization, the operator might receive confusing and contradictory messages, which has negative impact on user experience.

Mechanisms need to be in place to ensure that equipment can be stopped automatically in abnormal situations – like a machine malfunction, a collision, or the presence of unauthorized personnel. Teleoperated equipment may require additional sensors and functionality to detect potential risks and enable safe remote fault handling and recovery.

The communication requirements for remote operation can be summarized as follows:

- ease of deployment
- minimum bitrate
- low latency
- reliability
- security
- emergency handling and recovery

Solutions and enablers in 5G

5G innovations related to media delivery, and core, radio-access and transport networks [6] will provide the technology needed for remote operation and other industrial mission-critical cases.

RAN solutions

To deliver an acceptable level of service experience for industrial remote operation, a number of performance requirements need to be set: minimum bitrate, maximum latency, and a permitted level of packet loss. By deploying service-specific optimizations relating to scheduling, the requirements of several remote use cases may be met by modern LTE-based cellular systems. And as LTE will continue to be enhanced with improvements such as latency reductions, it will become ever more applicable for industrial applications.

However, some demanding use cases – such as the operation of fast-moving machine parts or scenarios that require accurate real-time control – place such stringent requirements on connectivity that they cannot be met by existing cellular solutions. But 5G technologies are being developed with these requirements in mind. With market introduction due around 2020, they will be able to provide the performance capabilities necessary for demanding industrial use cases. In 5G, innovative air interfaces like NX will be developed that include sophisticated signaling methods. The evolution of LTE will be a significant part of 5G, and its technologies will coexist with NX.

If an industrial site is located within the coverage area of a mobile operator's 5G network, remote services can be provided to the site using the network's inbuilt mechanisms at the required performance level. In many cases, however, industrial sites tend to be located in areas without adequate 5G coverage. In such cases, a dedicated 5G infrastructure can be installed near the industrial site, which could be either permanent or temporary.

To support the requirements of the whole coverage area for high-load situations, special design characteristics need to be taken into consideration. The challenge arises when connections are congested or suffer from poor link rate, causing the transfer rate over the radio link to drop temporarily below the code rate of the video stream. When this occurs, queuing delays follow, which in turn degrade user experience.

Low latency and high reliability are two key design criteria for the NX-radio interface in 5G. To attain the levels of performance required for latency and reliability, a number of air interface design characteristics, like short radio frames and new coding schemes, will come into play.

To achieve low latency in the system, the time it takes to transmit a control command over the radio interface needs to be minimized. In NX, the time to transmit a single packet over the air – the Transmission Time Interval (TTI) – is expected to be a fraction of the TTI in LTE. The TTI in LTE is defined as 1ms, whereas NX will be designed to deliver TTIs in the order of one or a few hundred microseconds [4]. Such low-order TTIs will enable short transmission times for short packages and facilitate retransmission without exceeding the latency bound.

The radio receiver needs to be able to decode received messages quickly. High-performance forward error correcting codes, such as turbo codes traditionally used for mobile broadband, are not optimal for transmission of short messages with high reliability requirements. Therefore, special forward error correcting codes such as convolutional codes are envisioned for latency-critical applications [4].

A highly reliable radio link is needed to avoid transmission errors and time-consuming retransmissions. The level of reliability needed can be achieved with high diversity order of the communication through antenna or frequency diversity, which improves the probability of signal detection and correct reception of the transmitted radio signals.

Messages need to be transmitted over the communication link without scheduling delays. To minimize delays, service-aware scheduling algorithms can be applied to prioritize critical remote applications over other less critical communication.

Core network aspects

Traditionally, mobile core networks are optimized to deliver a specific set of operator services. This approach was successfully applied in the rapid upscaling of mobile-broadband services for global reach. By adding flexibility to the core network architecture, 5G solutions will take optimization one step further, facilitating a much wider range of services and use cases beyond mobile broadband.

One way to provide flexibility is through network slicing: the logical partition of networks into slices supporting a defined set of devices and services. Through slicing, a single physical network acts as multiple logical networks optimized for specific use cases or business needs. Resources may either be shared among several slices allocated on demand, or dedicated in advance to a given slice. The network operator decides. The functionality provided by a network slice can be tailored to a specific given use case, so the network features meet the business need and allow for cost optimization.

While physical network resources can be used to create network slices, the concept is particularly well suited to virtualized resources. Cloud technologies together with Network Functions Virtualization (NFV) provide cost-effective tools to adapt network functionality. In combination with software-defined networking (SDN), these techniques enable network operators to adjust their networks to meet the specific needs of industrial use cases.

The technologies needed to enable network slicing are emerging. In the 3GPP DECOR (dedicated core network) work, mechanisms have been defined to redirect a UE to a given network slice, based on user subscription or some other configuration information stored in the network. This work may be extended to include optimization of a network slice for a given use case.

Specifically, a number of link characteristics – like reliability, delay, and security – need to be considered to optimize network slices for industrial applications like remote operation.

A greater level of reliability can be achieved by adding system redundancy for computing, data, and network resources, and the associated control mechanisms for high availability.

Moving core network functions closer to the network edge reduces transmission delays in mobile-broadband networks that have centralized core network functionality. To cater to extreme cases, core network functionality can be colocated with RAN entities to avoid additional latency.

Deploying user services on local cloud platforms reduces latency. Extremely low latency capabilities can be provided by reusing the same execution environment for mobile-network radio and core processing, and for service functions.

The solutions that today's industry devices use for timing synchronization are independent of the mobile system. However, the air interface in 5G systems will provide accurate timing synchronization. By reusing the mobile system for timing synchronization, overall system complexity can be reduced.

A network slice may be optimized to serve a limited geographical area. If a single base station can cover the area, support for handover may not be needed. For areas covered by just a few base stations, the mobility solution may be optimized for the specific use case – and so simplification in system operations and deployment can be achieved.

The mobile network can be adjusted to use the identity schemes and security mechanisms tailored to industrial applications. For example, if an identity management scheme has been implemented on a local industrial network, the same identities could be reused in a mobile system – removing the need for an additional mobile system identity scheme.

Certain functionalities like advanced charging schemes, policy functions, and circuit switched interworking – which are fundamental to a public mobile-broadband service – are unnecessary in networks supporting industrial data applications. The resulting industrial system is more operationally efficient, which brings cost benefits.

Applications can explicitly indicate their communication requirements, which are translated into parameters for the underlying radio access and core networks. These parameters are considered in the orchestration and configuration of network functions as well as the transport network.

INDUSTRIAL APPLICATIONS can be supported over logically partitioned network slices running on top of a generic network, or over dedicated industrial mobile networks – independent of the public network. A dedicated custom deployment could be offered by a traditional mobile operator or by a third-party player. A hybrid solution offers additional flexibility, as standalone functions can be deployed on a dedicated network, while others can be supported by traditional operator services. The best approach can be worked out depending on the specific technical requirements and business setup of each deployment. To offer a truly flexible and global solution, the ability to set up network slices dynamically across network operator borders according to specific needs is required.

Low latency transport

To support applications like industrial remote operation over long distances (up to thousands of kilometers), transport networks need to be able to provide adequately low latency for the service at hand. Certain applications, like the excavator one, where operations take place in remote locations may require connectivity services at a given place and for a defined amount of time. The connectivity services needed to support applications like this require flexible and dynamic provisioning – possibly in several transport networks and potentially across multiple administrative and technology domains. Today, the provisioning process can be cumbersome and costly. But SDN and network orchestration promise to provide more flexible provisioning of transport services. By using these technologies, individual SDN domain controllers expose an abstraction of resources to a higher-layer controller/orchestrator, which in turn creates a global view of resources – facilitating provisioning of E2E connectivity services with given characteristics.

In theory, the maximum point-to-point distance providing a one-way-latency budget of 10ms (needed for haptic control) is given by the propagation delay of light along the surface of the earth – which for fiber corresponds to approximately 2,000km. In practice, recorded latency in transport networks is significantly greater than the theoretical value because of the lower physical layers and transport protocols. First, the actual signal path through the transport network is longer than the direct path between two points. Measurements show that the actual path is approximately 1.5 times greater than the direct path [7]. Second, the median fiber path between routers increases the length of the signal path by an additional factor of two. Other factors that affect the practical minimum latency achievable besides propagation delay are transmission delay (which is of the order of milliseconds), processing delay (which is negligible), and queuing delay (which depends on traffic management).

To guarantee low latency, transport networks need to provide mechanisms that can apply priorities and enable optimal routing of latency-critical traffic. In practice, such mechanisms might select direct paths to minimize propagation delay or bypass certain nodes to avoid the delay incurred at intermediate hops – allowing overall latency to approach the theoretical limit.

Media delivery

Compression is a significant feature of any media-based solution that uses a mobile network to provide connectivity. The purpose of compression is to decrease bandwidth utilization, but it adds

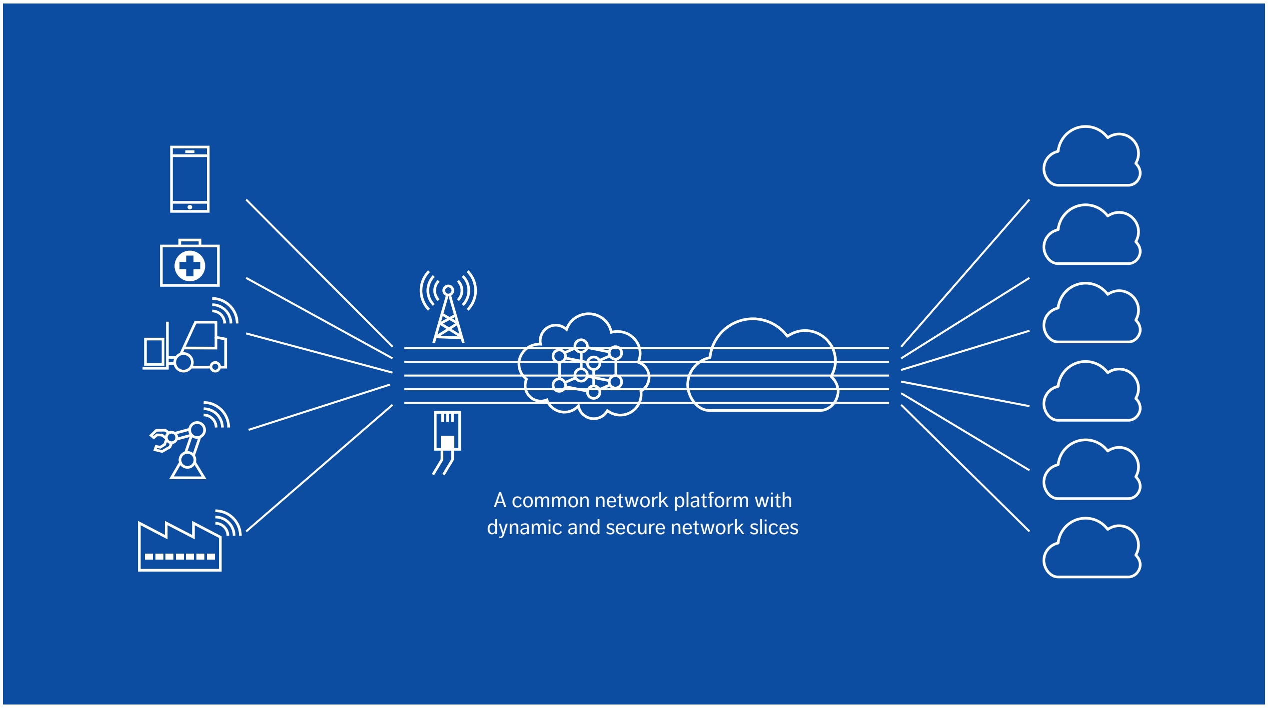

Figure 5: Resources for different industries – logically separated through network slicing

latency, and so compression algorithms need to be highly efficient. IP, UDP, and RTP are the most commonly adopted protocols for transmission of real-time application media. UDP is the best for minimizing delay, but as it is inherently unreliable, techniques such as forward error correction (FEC) or retransmission need to be used to manage packet losses. However, FEC and retransmission add to the overall delay, and so to minimize the dependence on such schemes, connectivity for remote operation should be provided over highly reliable networks.

Most remote operation applications will require a high to very high level of security. The Secure RTP (SRTP) protocol can be used instead of the RTP protocol to meet security requirements related to media delivery.

Transmission of application control signals

Application control signals in remote operation solutions include the signals traveling from the operator to the controlled equipment, which directly or indirectly control the movements and actions of the machinery. Control signals typically originate from control equipment like a joystick or haptic device. For haptic interaction and force feedback, control signals also travel back from the controlled equipment to the operator.

Reliability is crucial when transmitting control signals, but as it often comes at the price of higher latency, some remote operation applications may benefit by using unreliable transfer mechanisms (with sufficient error handling) to transmit control signals.

The Stream Control Transmission Protocol (SCTP) is suitable for the transmission of remote operation signals, as it provides real-time characteristics and allows the level of reliability to be set. Regardless of the transport protocol used, remote-operation applications need to manage network congestion and failures as well as transmission errors swiftly and safely.

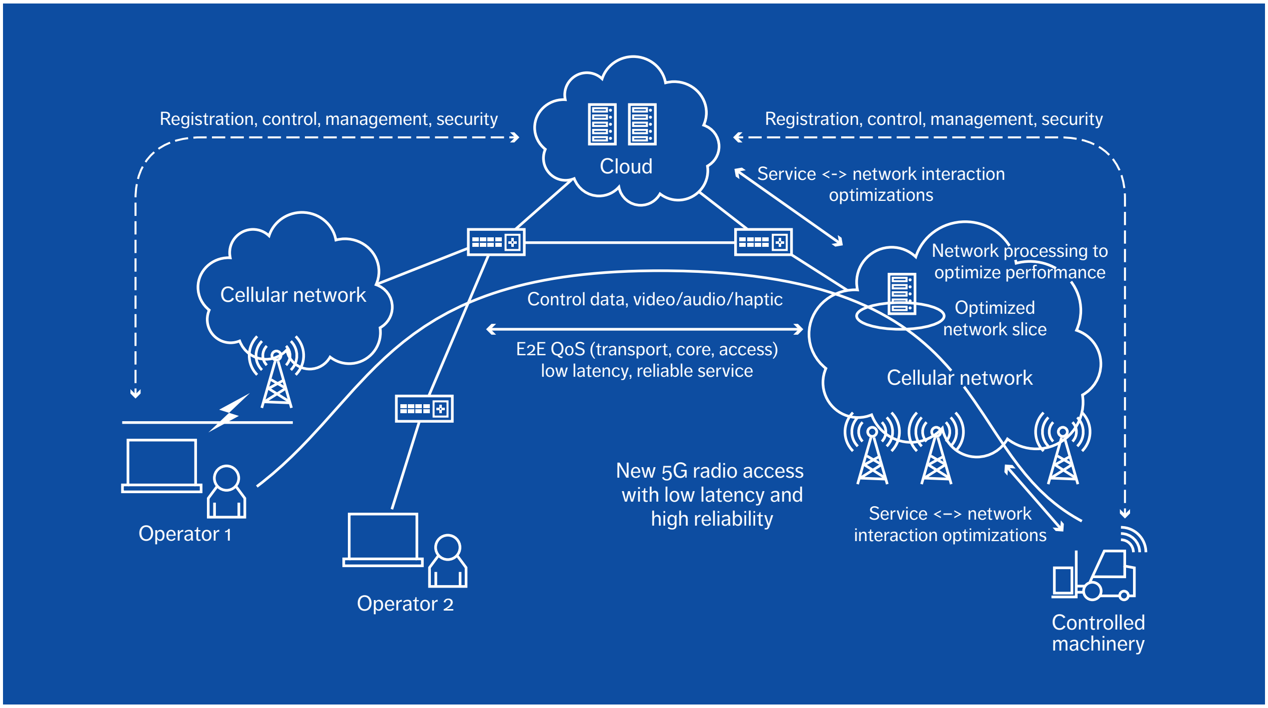

Figure 6:
Overview of 5G enablers for industrial remote operation

Conclusions

Examples of remote operation and control applications exist everywhere, but the benefits that can be gained in mining and construction are easier to realize than in some other industries. Increased productivity, access to specialized expertise, improved safety and wellbeing, and reduced exposure to hazardous chemicals are just some of the gains that remote operation can bring.

If configured appropriately, today's LTE networks can support some industry applications, but the needs of other, more demanding, use cases can only partly be met by existing communication solutions. 5G systems are, however, being developed to meet challenging requirements like low latency, high reliability, global coverage, and a high degree of deployment flexibility – the key drivers supporting innovative business models.

Together, Ericsson and ABB are working on remote operation and how industrial use cases can be developed into new value propositions for the Networked Society.

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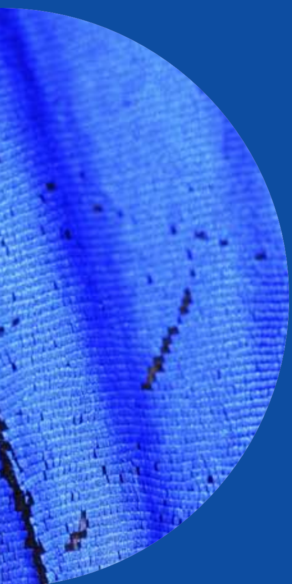

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