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Chapter 5: Managing and orchestrating the complexities of next-generation mobile networks including 5G and future wireless protocols

5.1 Introduction

Mobile communication has been one of the most mass-deployed technologies in human daily life. The demand for mobile wireless systems with the ability to provide universal, omnipresent broadband services is rapidly increasing, and vested efforts to achieve this goal have materialized as a succession of mobile network generations ranging from 1G to the latest 3.5/4G. The imminence of such a requirement becomes more obvious as an ever-increasing number of vendors show their confidence in the commercial successes of future mobile technologies, which would be worth trillions of dollars in the market. Following this path, the research field has progressed through the tidy track laid down by the need for practical solutions for the next-generation mobile networks lying ahead of the current evolution pathway, including the finalized 2020+ 5G technology, “B5G” (i.e., Beyond 5G), and NR-U (Unlicensed 5G New Radio).

The condition for the 3GPP specifies three usage scenarios: Enhanced Mobile Broadband, Ultra-Reliable Low-Latency Communications, and Dense Deployment of the IoT. It explicitly defines three technological capabilities named Enhanced Mobile Broadband, Ultra-Reliable Extremely Low-Latency Communications, and Large-Scale Connection of the Massive Volume of Devices to support three market objectives. While the large-scale bandwidth requirement for next-generation devices increases and varies based on their various usage purposes, with the growing demand for versatile communication capabilities to support the enhanced data access experience in the 5G era, conventional filtering techniques may face their bottlenecks.

5.1.1. The Evolution of Mobile Network Technologies

In the last thirty years, five generations of wireless cellular networks have matured, providing mobile communications to over 5.5 billion customers. These arrived fifteen years apart: the first generation, 1G, was analog and the second, 2G, was digital. The third, 3G, adopted high-speed technology and evolution. The fourth, 4G, was the evolution, which maximizes available bandwidth to provide very high data rates. 5G, the fifth generation, differs from the evolution it will replace in its increased flexibility, allowing it to serve diverse applications with wide-ranging capacity requirements, latency constraints, and energy and cost sensitivities. Efficient spatial usage will also be important: improving outdoor coverage and especially indoor coverage, with smart coverage solutions like and (or 'small cells'). Aspects to be considered are the necessary density of small cells to achieve coverage, the complementary appetite of the already deployed network, and the cost in terms of connections and cooperative meshing. Cell density may be very high in urban contexts, for example reaching -, whereas much larger cells achieve coverage of suburban areas and the countryside, assuming tens of kilometers -, and of some interstate communications.

To increase spectral efficiency, can be used to increase the bandwidth and an elaborated multiuser may be exploited to control interferences. Although quantum jumps are not conceived in terms of performance, a capacity one thousand times that delivered by is identified. The novelty, this time, however, lies in the design and functionalization of the network architecture, to guarantee these performances. To ensure this capacity the network architecture must interact and evolve dynamically in response to fluctuations in traffic patterns, ensuring adequate saturation of the load. Only then can we expect a perceived quality of service closely correlated with user experience. These specified conditions represent the current and possible future guidelines behind the design of next-generation architecture, equipping the network with an increasing level of knowledge. The network in 5G will indeed manage itself and exploit the expertise, originating from enhancing information on the geographical coverage status, that will be distributed intelligently to actively support deployed management entities.

5.2. Overview of 5G Technology

A 5th generation (5G) system is expected to make use of several distinct technology enablers that will become available towards the horizon, i.e., from 2020 onwards. These technology enablers will shape the design of entire layers in a next-generation radio access network (RAN) architecture, starting from physical layer algorithms up to radio resource management algorithms (Foukas et al., 2017; Afolabi et al., 2018; Li et al., 2018). At the same time, the densification trend already observed in 3G and 4G networks is expected to continue, exacerbated by the need for a dense, primarily small cell infrastructure also for the support of mission-critical scenarios, as well as in anticipation of the expected high number of devices and emerging Internet of Things (IoT) applications. From a networking perspective, a corresponding logical investment has to be made, targeting software-defined network (SDN) and network function virtualization (NFV) projects applicable to RAN architectures.

The 5th generation (5G) mobile and wireless standard is currently being developed and is planned to be operational by the end of the decade. 5G is expected to support up to 10 Tbps/km²; as an example, this would correspond to multiple HD videos streamed to all of the households in Manchester being played simultaneously without interruption, using only a single 5G cell that could be located in the city center. The 5G system is still in its infancy but is expected to be very different from existing 2G, 3G, and 4G networks. At the time of writing, 5G is called to support so-called “use cases,” i.e., rather distinct services with rather distinct Quality of Service (QoS), and it is a nonlinear optimization problem of how to efficiently engineer a single mobile network to do this; actually, the responses to the question might be rather different depending on the political system and on the society the mobile network has to support.

Fig 5 . 1 : 5G Technology

5.2.1. Key Features of 5G

Substantial growth has been witnessed in the speeds at which customers seek information and data, and this trend is expected to continue. 5G is estimated to have speeds up to 10 times faster than the fastest speed currently offered by 4G. High speeds of up to 10 Gbps are anticipated to support connections to 100 devices. Latency, from an average of 50 ms in 4G, is expected to be reduced to a maximum of 1 ms in 5G, making it better for time-sensitive applications. 5G will facilitate a connection density of 1000 times more than 4G, which will support better connections in dense usage areas, such as amusement parks, city centers, and stadiums.

The 5G network is expected to provide a true broadband experience across a wide range of connected devices and applications, providing both high speed and high reliability coupled with low latency. The 5G device range is expected to remain low, from between 100 Kbps to low speeds of 10-100 Kbps. 5G promises greater efficiency in terms of energy, leading to support for greater device range and device density serving applications of machine type and mission-critical control. In 5G, it is not the mobile phones that gain the most; rather, the technical improvements of the 5G network benefit a much wider area of applications, such as driverless cars, medical machines, and factories hosting IoT applications.

5.2.2. 5G Architecture

The 5G next-generation mobile communications system is rapidly attracting attention for its expected technology and high growth potential. 5G is expected to provide a variety of services in society, such as enhanced mobile broadband, ultra-reliable and low-latency communications, and massive machine-type communication. To realize these services, the 5G network needs to be able to respond accordingly to the large and different traffic conditions according to the service characteristics. To achieve this, dense and diverse radio access networks are being studied, but nothing is clear as to which one is appropriate. A multi-carrier non-orthogonal multiple access method using a programmable distributed architecture is proposed, describing its specific function configuration (Rost et al., 2017; Zhang et al., 2019).

An overview of the 5G network architecture is shown. The centralized RAN configuration shows the baseband unit unified at a centralized point, with low-cost remote radio heads at each cell. The baseband unit and remote radio heads perform their functions using a specific interface and transmit the received and transmitted bit streams through their fronthaul. Furthermore, with the advancement of centralized RAN, each baseband unit can perform the end function using disaggregation, and a few or all of the functions are executed at centralized locations. This configuration has the advantage that the Centralized Unit that controls each baseband unit can flexibly manage each cell. Also, since the baseband unit can be located in a data center with a facility, scalability is possible both flexibly and cost-effectively. On the other hand, in the centralized configuration, if the functions are disaggregated, higher and more tightly redundant networking is required on the link.

5.2.3. 5G Use Cases

The large investment in 5G systems compared to 4G/LTE systems highlights the fact that 5G is not just a faster step on 4G, but is a genuine revolution when it comes to the services that are offered, to the dynamic mode of traffic forwarding and reception, and more generally, to the relationship between the end user and the service provider. With so much at stake, it is important to anticipate the new use cases related to 5G and to foresee mechanisms for meeting the requirements of the emerging mobile services. The full exploitation of a quantum leap technology such as 5G has to far exceed, conceptually, the choices that emerged when the standards were produced, driven by the implementation of ordinary voice calls on a cellular infrastructure.

In 5G, new services are expected, including ultra-high-definition streaming, virtual reality/augmented reality, and vehicle-to-X communications. These typically use very variable bit rates, with different characteristics, from bursty to isochronous, single-user to multi-user, often requiring very strict latency constraints. These new services will also demonstrate very different traffic patterns, potentially changing over a very short time scale, leading to demand to possess a very flexible mode of operating the access networks as a whole. A unique infrastructure that differs only in the mode of operation from the current mobile system to one only partially capable of supporting a certain kind of service.

5.3. Future Wireless Protocols

The use of adaptive antennas should provide significant increases in network capacity without increasing the number of cells per service provider. However, there are several open issues to resolve that will enable adaptive antennas to provide wide-area service gains in practice. For example, how should we design time, frequency, and adaptive array patterns to reduce interference and provide service gains over the varying range of different user equipment? Given the current standards, which use orthogonal frequency division multiple access with multiple input and multiple output transmission schemes as the physical layer, what simple antenna array processing can be employed that does not interact with the existing receiver? We note that the work in multiuser detection is for interfering spread-spectrum codes and does not yet provide collaborative processing in the spatial domain for OFDMA.

We posit that the use of cross-layer design techniques will be necessary for realizing the potential of multiple radios and antennas. Adaptive arrays provide clear path gains once they have served to separate signals spatially. Hence, data rates will be known. It is useful to provide guarantees for end-to-end fairness, such as those employed when implementing quality-of-service guarantees. By doing so, multiple service providers can share a network. To do this, physical layer design must necessarily communicate with higher-layer protocols. Such extended models of wireless networks are few and likely require new queueing models and some real-time protocols to schedule packet transmissions. However, this complex design interaction yields complex protocols where operation incurs high coordination costs for managing interference.

5.3.1. Emerging Technologies

Enhanced Mobile Broadband (eMBB): Seen as an evolution of current 4G services, it aims to meet the growing needs of today's mobile users that correspond to the simultaneous access of film and audio streaming, online gaming, social networks, downloading and uploading large files, and others. On this basis, eMBB addresses high traffic density areas such as user concentration, per unit area, or at peak times, ultimately providing users with fiber-class connectivity. Ultra-reliable and low-latency communication (URLCC): Addresses cases that require high reliability and low latency in the communication link, even in the presence of high user mobility and low user density. Use cases as diverse as autonomous driving, tactile internet, and remote surgery, among others, require this service. The key performance indicators for URLCC are the transmission delay between the time that a message is sent and when it is received, the link quality, both for the uplink and downlink, at a 99.9999% level of confidence, and packet loss rate for the user equipment. Massive Machine Type Communication (mMTC): Suitable for supporting a large number of IoT-capable devices that are distributed concurrently along a network, e.g., broadcast, multicast, and unicast. The sectors set to gain from mMTC are several, including smart cities, public communication systems, smart grids, intelligent transportation systems, and others. mMTC services contribute to increased coverage, reduced delay, and power consumption, better energy and bandwidth management, higher speed rates for long-term support of up to 10 years without the need for battery recharge, and greater scalability to several 1,000 active devices per km² in urban environments to 100,000 active devices per km² in an event.

5.3.2. Comparative Analysis of Protocols

In this section, we summarize the general features of some commonly used routing and transport protocols in traditional IP networks. The summarized features of routing and transport protocols are limited to the most important aspects that are requisites for providing QoS. However, the attributed summaries are not comprehensive. Their purpose is to elucidate why these common protocols are not adaptable to the requirements of next-generation mobile networks in terms of QoS or cost, but not to discuss the complete functionalities of these protocols.

1 Comparison of Routing Protocols In general, different routing protocols were designed for different types of objective applications. The four most common protocols are Bellman-Ford, Dijkstra, IDRP, and OSPF. They offer different performances in terms of routing stability, the processing time to generate paths, and robustness. However, except for some recently proposed integrated or QoS routing protocols, they do not take QoS and costs into consideration when selecting a routing path. Their routing decision is based only on the destination address; also, the selected path will remain unchanged until a route update is received. This could lead to poor network performance, especially in mobile ad hoc networks where frequent topological changes can occur. These routing protocols are not effective in real-time mobile Internet applications caused of the problem of route refreshment between real-time communication pairs, the appearance of unexpected route delays, and finite battery power.

5.4. Challenges in Mobile Network Management

Incorporating a large number of systems, each of which includes its complexities, the efficiency of management significantly influences the potential profitability of mobile service provision. Regarding profitability, compared to personal computers or TV operators, the value of individual access devices is quite modest. In addition, the intrinsic value of call services is less than that produced from the advertisement access that the service permits, as might be performed by a TV or a computer. Consequently, based on an analysis of the exploitation of resources found within current telecommunications networks, it appears that there are potential market sizes on the scale of subscribers (even though management costs associated with the operation of larger current wireless systems would preclude them from reaching these levels). Based on these observations, it is reasonable to suggest that future management capabilities for realizing the full potential of large personal access systems are going to be increasingly central to achieving successful mobile business models.

5.4.1. Scalability Issues

Scaling out wireless networks introduces some fundamental changes in their architecture and perceptibly increases their complexity. Typically, any mobile network consists of operators' core data network, access network, and user devices connected to the network edge through radio interfaces. Between the core and access networks are intermediate mobile network access elements connecting the edge nodes with the core of the network. With the increasing demand for capabilities and performance of wireless networks, core and backhaul network nodes, and related infrastructure should provide reliable communication for a much larger number of wireless endpoints, generate lower-latency responses, and support bi-directional multimedia traffic efficiently.

Integrating communications of both present and future wireless data applications and wireless network functionalities, the next-generation mobile networks are planned to fulfill the increasing consumer and business demand for quality-of-service wireless data and support billions of wireless nodes generated in the upcoming era of M2M applications. Consequently, any future wireless mobile network with support for various short/large-range multimedia data applications should scale up. Can it be scalable and sustainable to support future networks which can host a combination of social/entertainment communication and new M2M applications?

5.4.2. Latency and Reliability

Data transmission in mobile networks is not reliable with a high probability because data transmission can fail for many reasons, such as noise, large reflections, insufficient power levels, Doppler effects, and the limited sensitivity of mobile stations. To achieve reliable transmission, it is necessary to transmit the data several times, which greatly increases the average latency. To reduce latency, we need to increase system reliability but also make reliable transmission with a high probability unnecessary. Essentially, we have to reduce the packet loss probability to acceptable levels. There are two fundamental methods for reducing the packet loss probability: increasing the signal quality and providing robust multicasting. A next-generation mobile network system must ensure voice and video quality of service like the current fixed wired mobile networks. Especially, the system should provide a reliable voice quality of service in a highly populated area of mobile communication if the mobile environment is undergoing a high-speed revolution. However, the conventional mobile IP-based network system has difficulty providing short transmission delays as well as reliable voice quality of service packet control overhead. Therefore, this proposes an autonomous quality-of-service control mechanism that is especially suitable for routing with quality of service in the case of the high-speed revolution of mobile communication.

5.5. Orchestration Frameworks for Mobile Networks

In a complex network domain with heterogeneous, overlapping functions, a lightweight, model-driven framework called Multi-Service Converged Orchestrator and Enhanced Control (MSCOEC) is designed. MSCOEC receives the high-layer view and low-layer view of the targeted environment and already deployed complex network service from the registration client, and then tunes and extends its foundational model based on a set of object-classifying and function-name-checking algorithms. Finally, a sequence of dynamic model maintenance algorithms is proposed to manage the exerted orchestration and control lifecycle.

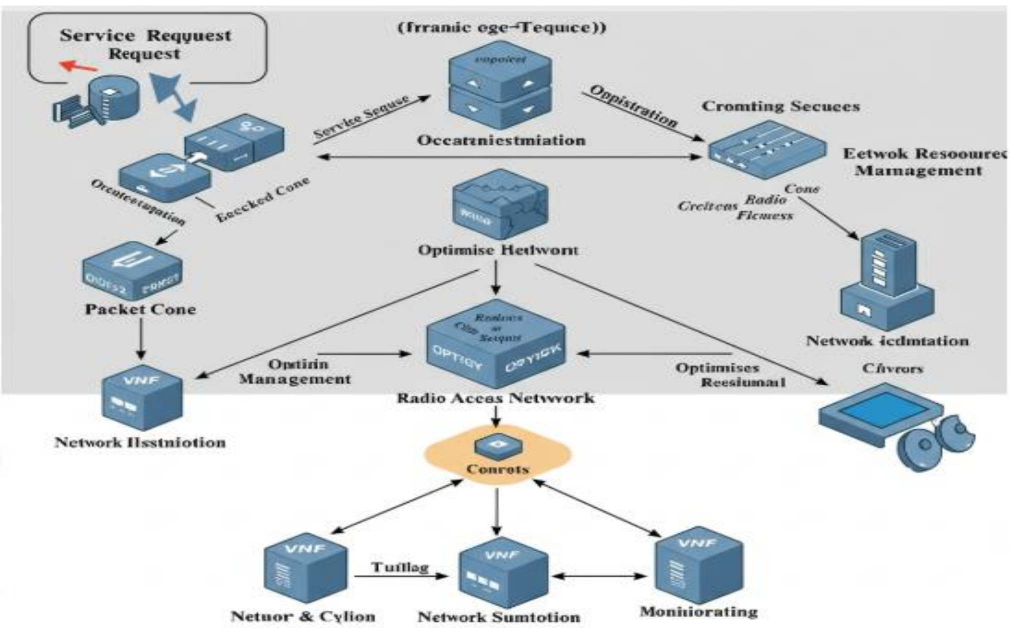

Fig 5 . 2 : VNF-Enabled 5G Network Orchestration Framework for Slice Creation

To minimize the discussed control deployment and maintenance challenges, we proposed the MSCOEC framework. Proof-of-concept experiments show how algorithms can receive notifications and extend the retrieval span and download chain of control model objects from the network model, and how management techniques are applied to another key algorithm. Further, real-life demonstrations highlight the outstanding performance of our recursive algorithm in generating queries toward simultaneously supported network control functions.

5.5.1. Role of Orchestration

To establish a common framework for the efficient and profitable operation of mobile networks, careful consideration must be given to the potential parts that may be required if a market for cloud or cloud-like network functions is created. Failure to do so could result in the value chain for network function virtualization and software-defined networking being competed away for little benefit to the network operators. This chapter describes some of the services and functions that might be significant. There may be opportunities for operators to offer the cloud orchestration functions themselves, utilizing the same core infrastructure as the network functions. Operators can offer special services at their local data centers for the virtualized network functions to improve delay and reduce the number of hops required to reach a network component. If operators plan to monetize their own data centers and cloud orchestration functions by providing the service end-to-end, their success may partly rely on moving to a role that includes some or all of these functions. These should reduce the cost faced by the independent component suppliers, who may then happily accept these roles for operators to continue with their special role as efficient integrators.

5.5.2. Automation in Network Management

Contemporary network management is operationally complex and is a key barrier to the deployment and effectiveness of networking innovations. From the plethora of existing protocols and their aggregation and variation in operation across different networks, it is difficult to get consistent behavior across elements and to reliably manage networks. The proliferation of devices, features, and services results in operational issues arising from the overwhelming scale of the network and the user demand set. The situation is not improving with new technologies. Evolving technologies like software-defined networking and network functions virtualization separate management and control from data flow and introduce elastic per-flow resource allocation, leading to even more dynamic network conditions.

By improving management complexity, automation can assist in reducing network downtime and improving security and configuration validation. Route optimization, management of network congestion, quality of service management, and security are all currently conducted through automation. Automation is already pervasive in network management in areas such as performance monitoring, accounting, and assurance, reducing human error and attending to repetitive tasks, service assurance, configuration, change, and fault management, and operational support systems. Devices may also execute partial automation, and networking solutions with proprietary functionality. Device interfaces can significantly impact the development of automation tools. Software vendors can further complicate this by being structured as a set of disjointed devices. This can result in limited access to and use of device execution state.

Overall, using automation, network management seeks to decrease complexity, minimize error rates, reduce operational costs, attempt to consolidate workflows, reduce costs by developing generalized solutions through modularity, standardization, and abstraction, keep track of devices and collaborative services with networks, and ultimately be adaptable. Such goals can be attained through shifting information, and working on declarative APIs that define goals as opposed to specifying methodological steps. This allows constructs to be made for legacy systems with the same API that is used for modern virtual devices and can also express more sophisticated solutions, mapping specific demand to generalized resources. In addition, device plug-ins may change the way automation can be shared among various networking services and service operations. Control of individual devices at lower layers must be developed with cooperation and transparency to account for different perspectives across a regional network. Device configuration can also affect automating access and delivery. For instance, simulation produces editions of actual devices for configuration and backup. Control planes need to operate in a consistent, open manner through structured, declarative, and often recursive architectures rather than through vendor-provided command-line or programmatic adapters. Automating comprehension should be better linked to the mapping of data sets by data models and to alignment with communication and dissemination standards. Finally, the automation loop supports a broad view of network management. To achieve successful network automation impact, the optimization potential of the loop needs to be recognized as a whole as a collection of cooperative features.

5.6. Security Considerations in Next-Gen Networks

In addition to handling the complexities of managing and operating future mobile networks, the need for carefully addressing the security and privacy requirements becomes very important due to the increasing threats of user data leaks and cyberattacks. In this section, we take a quick look at various security considerations. It should be remembered that addressing this security requirement should not degrade the quality of service of the network in various measurements such as average data rate and system delay. An ideal next-generation mobile network should provide the capability for more users to access the network at higher rates, should be securely protected against all cyber threats, and, most importantly, should be energy-efficient, ensuring sustainability and preventing global warming. However, these security requirements pose a large number of constraints and overheads that are difficult to achieve in the currently deployed networks.

5G is expected to offer network services at a very large scale compared to the current network. Unfortunately, with increasing service offerings and priorities of network-based applications, it is unquestionable that there exists a risk of data leakage. We believe that the current network risk policies need to be modified to better cope with the increasing service demands. To address the challenge of user data privacy, a privacy-preserving data handling system can be designed. Such an environment will enforce clear lines of accreditation and privacy of personal data and also punish malicious insiders who violate key access control patterns, preventing data leakage. Due to the increasing physical proximity of the cloud data centers, which translates into high-speed wireless access to the cloud, attracting high-density network hotspots such as cities into highly centralized, potentially catastrophic cyberattacks. To manage the cybersecurity issues, our system can enforce and monitor a focus with monitoring tools that will examine large data streams searching for national patterns and unauthorized espionage, like the insider scope of privileges being utilized for personal exploitation.

5.6.1. Threat Landscape

Recent years have seen an aggressive move toward the development and support of next-generation wireless technologies and concepts. Although next-generation networks stand as a revolutionary economic asset capable of connecting people, apps, networks, and things, recent advancements in technology and deployment have not been matched with equivalent attention to security threats. Concomitant risk monitoring and threat data sharing to develop incident-centric countermeasures are crucial, as is increasing security awareness and the evolution of effective cooperative security frameworks. The Internet architecture's security predicament translates with enhanced intensity into the complex next-generation mobile networks being developed to answer the ever-increasing demand for capacity and service requirements.

Recent threats and real-world incidents striking mobile communications and data sharing include the capability to deny service by utilizing device-specific channels, among other incidents that are considered absurdly bizarre, involving the hijacking of customer information to ease illegal immigration, or siphoning cell phone-based location data and billing information. Phreaking still plays the same four pillars of technical attack, but motivation has evolved from a desire to hear other people's conversations to laying traps while targeting the inexperienced, uneducated, and irresponsible. Although advance fee phone fraud is often stipulated as one of the root triggers of the victimization process, other less obvious interconnected details come into play to help scammers optimize returns. Social cognitive theory is postulated as a suitable frame because the modem operator can watch call activity and, by using the previously purloined personal details of the account holder, provide necessary pointers and insights to ensure high earnings on thousands of prey efforts.

5.6.2. Mitigation Strategies

In the previous sections, we discussed various complexity challenges that operators are likely to face in next-generation networks. In this section, we explain numerous mitigation strategies that could subdue these complexities in next-generation networks. We hope to show network operators that despite next-generation networks being more complex, they have at their disposal methods to reduce the level of complexity. The first and probably the most important strategy for network operators to mitigate complexity challenges is to provision accurate metrology resources to measure the impact of traffic parameters and characteristics on the network. Network operators should use these statistics to clearly understand network traffic. By continuously monitoring traffic parameters and behavior, network operators gain insight into their network behavior and can predict future behavior. By using metrology tools to measure these parameters, network operators understand the character and intensity of the traffic that traverses their networks and are therefore more capable of accurately evolving the network in reaction to expected future traffic patterns. Such capabilities significantly reduce complexity. Other complexity reduction strategies include predictive caching systems that reduce long-tail requests that generate high-complexity queue dynamics. A proactive caching mechanism keeps well-informed content that is expected to be popular in the network, capable of quickly forwarding this popular content when required, thereby decreasing peak traffic and queue dynamics. Furthermore, software-defined networking can assist in making next-generation networks better able to meet operator requirements in the form of reduced complexity in abstracting common network functions. Automation of everyday tasks required by network operators is also crucial to avoid human error that can lead to network incidents. By centralizing system support tasks, errors can be detected more easily, and eventually, the majority of them will be removed. Lastly, the connection of peer-to-peer traffic can be transported during quiet periods of the day on the network, also reducing peak times. Additionally, new scheduling, admission control, and routing rules require the potential to make such optimizations.

5.7. Regulatory and Compliance Issues

Next-generation mobile networks are exposed to many regulatory and compliance issues. Due to their varying dynamic characteristics and ability to segment the infrastructure, mobile networks raise numerous spectrum policies, competition, interoperability, and security concerns. Depending on how devices dynamically slice the infrastructure, spectrum policy may require updating in novel ways to allow diverse types of spectrum users access rights to utilize portions of the infrastructure. Slicing the infrastructure may also raise network neutrality issues—especially if a model comes to underlie the infrastructure.

Competition concerns also exist. For example, in the market for mobile voice, many studies demonstrate that consumers complain about having only a few providers to choose from. Incumbent providers may take action to support their service offerings when they face increasing competition. Indeed, the communications industry has a history of using technological advances to differentiate services that could be delivered over a more generic platform. Therefore, policies regarding type approval of access to the evolving communications platform must be established and also need monitoring. Interoperability, the ability of network elements to successfully communicate, also requires close monitoring because insufficient adherence to standards can lead to consumer frustration and increase third-party costs. Lastly, increasing security in a software and data-driven environment raises significant concerns for next-generation mobile networks. Users need secure systems to rely on for the multitude of tasks they perform with mobile devices. At the same time, the peculiar nature of mobile devices, particularly how a mixture of devices can dynamically reconfigure to slice the system, makes security metrics such as reliability and assurance difficult. Protecting a complicated multifaceted architecture from the myriad of threats it faces then becomes a significant issue. In this chapter, we briefly consider next-generation mobile network regulatory and compliance issues from a technological perspective with a focus on aggregate architectural concerns.

5.7.1. Global Standards

International Mobile Telecommunications has identified 336 requirements for the future of the global standard for mobile broadband. These standards encompass two approximate generations of technological development. The first generation will consist of commercial equipment that is standardized in releases up to and including Release 15, Release 15+, and pre-IMT-2020 submissions. The second generation of IMT-2020 will consist of releases from R16 to R17. It is important for research and network operators that a common structure is taken up by the original proposals and that the standard is restricted to those hard areas of interoperability that are difficult or impossible to solve as the standard evolves through Release 17. At the same time, it is important that the organization also keeps a research agenda that can handle radical changes that could address regional issues or bandwidth that lies outside the performance window of commercial projects of today.

5.7.2. Impact of Regulations on Deployment

In the United States, cellular communications development was guided by the adoption of a set of Domestic Public Cellular Radio Telephone Service Rules. They established a 40 MHz duplex channel frequency allocation and defined mobile transmitter power levels to assure system compatibility. Cellular service became subject to federal licensed jurisdiction about conditions on licenses and technical parameters. In 1994, the Digital Cellular Order established technical parameters about capacity and efficient use of spectrum. The assignment plan was revised. Another upgrade is expected in 2010.

At the end of 2005, the Commission initiated a proceeding to establish standards for the upcoming frequency auction. A major part of this "Second Generation of Innovative Wireless Services" is to preserve public safety by providing an interoperable 20 MHz public safety spectrum dedicated to the coverage of major population areas. It specifies technological requirements for voice and data services on 24 MHz of the 60 MHz license for commercial networks planned for the band. On January 15, 2008, the Public Safety Spectrum Trust Corporation was renewed. The D Block combined commercial spectrum, highway center, and a national public safety network for which separate auction policies should be established. Finally, the 55 MHz of usable channels are allocated for commercial, public safety, guardband, and federal/nonfederal shared use.

5.8. Future Trends in Mobile Networking

We specify eight general requirements beyond the current technologies to continue enjoying the fast growth and improvements of modern mobile networking. They

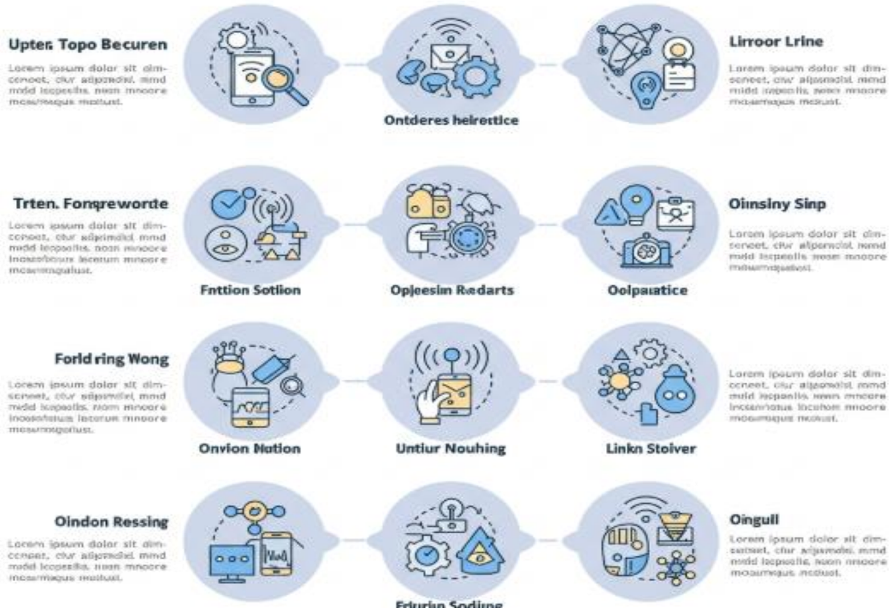

Fig 5 . 3 : Eight Technical Requirements for Future Mobile Networks

encompass the different user, service, and application requirements. The future gains would also come from 'intelligent' technology that can handle the inherent complexity and system limitations of future networks. Specifically, the eight requirements are: (1) integration of multiple key capabilities including the small and large wireless interfaces, small and large IP data routing, optimal transport and link resource utilization, plus joint mechanisms supporting different networks, data rates mix, loss tolerance, real-time and non-real-time service; (2) full and systematic exploitation of the opportunities provided through the mechanisms; (3) integration of wireline and wireless network integration plus simple wireless network-enabled technology; (4) move to expand a single IP address and a home network connection; (5) efficient multicast and broadcast support; (6) efficient support of fast dynamic channel adaptation; (7) mutual interference management in the presence of rate adaptive broadcast and multicast; and (8) closed-loop reverse link feedback and open-loop forward link registration.

The large body of existing work discussed in this tutorial serves us well in providing a strong base for new networking and radio access technology across a wide range of possible future systems and services. The paper also outlines the critical set of additional issues that must be addressed, confirming the well-known cross-layer complexity reduction and enabling limited feedback possibilities. We need to be careful in designing and exploiting future systems and applications because there are opportunities for expanding the existing seemingly 'marginal' vulnerabilities and limitations into more severe and difficult technical challenges. In some cases, the implementation of techniques and mechanisms reduces the vulnerabilities or limitations entailed with the new feature by harnessing the beneficial synergism between the future networks and their application environments. The ability to satisfy the following requirements would separate successful future telecommunications companies from less successful competitors.

5.8.1. Next-Generation Technologies

The increasing demand for wireless data services has escalated the efforts to define the fourth-generation (4G) mobile network and beyond. Although it is also recognized that more sophisticated methods and system-level optimizations are needed to enable the necessary system capacity and throughput, it is undeniable that the use of multiple antennas at both receiver and transmitter ends will play a central role in future mobile networks. This dominant role of MIMO is also signaled by the fact that it has become a part of the terminology through which the wireless research community envisions the future 4G mobile networks, namely MIMO-OFDM.

Exploiting the spatial domain is an effective way to gain improvements in channel performance beyond those achievable through increasing the cellular density or frequency reuse factor. The concept of multiple antennas at the receiver and transmitter to improve communication performance is commonly known as MIMO and has found a wide array of uses in communication systems in the last decade. Although MIMO has been prominently featured in the WiMAX base standards, it is not necessary to limit our analysis to WiMAX only. Considering trends towards integration at all system levels, it is expected that the 4G network to include the features that are common in systems like WiMAX.

5.8.2. Predictions for Wireless Communication

With user mobility increasingly displacing the spectrum as the primary driver of system complexity, wireless communication may approximate the ideal performance of wireline communication systems. While such performance looks like it may be achievable within the next 20 years due to advances in coding and adaptive techniques, we must control and reduce the complexity of network management and control protocols relative to the wireline case to meet the expected demand for wireless communication services. The lamination of the communication space can facilitate management and control by placing communication services at the user spacecraft; flexible allocation of communication resources on a per-call basis can control and reduce the complexity of network management and control functions; efficient management and control can be achieved by using existing wireline network protocols in situations where capacity approaches the desired capacity of the network.

Radiofrequency and optical wireless techniques will form a commonplace part of a citizen's environment over the next 10 years. Mobile and personal satellite communication services will be the bridge to information such as the Internet and the National Information Infrastructure. Capabilities responsible for success in the marketplace are being shaped by competitive forces that enable tactical decisions in the application of technologies to be made now. The subsequent development of common platform infrastructure, the construction of which is beyond the scope of user needs, will fundamentally shape the daily use of space assets. The communications applications discussed above are implemented in multimode, multiband communications terminals that rely on advanced techniques sharing integrated components to minimize total cost. These technologies are commercially successful by their use in large-volume, high-competition consumer and industrial applications. The complexity of future network control functions tends to augment management costs. The effective management and control of such communication networks impose several hard problems of computer and communications complexity that are more severe in the wireless environment than in the wireline case and are not, in general, capable of a known solution at this time.

5.9. Conclusion

With the migration of telecommunication networks development towards mobile networks, future standards must be conceived in a fully integrated perspective encompassing other standards aiming at global communication coverage. We have outlined four different kinds of embedding relationships with other fields. Current efforts linked to other similar projects are focused to a great extent on the third linked subject. It is through Systems Engineering that cooperation among different groups of expertise can be better fostered since it permits not only the introduction of rules to guide the work but also the standardization of the components used in systems, as happens in more specialized scientific areas. Finally, Systems Engineering makes it possible to incorporate the advances made in the embedded areas into a broader perspective, contributing to improving the performance of the systems developed.

The evolution from present to future mobile networks will take place through the introduction of several intermediate solutions. Given the great complexity involved, the migration path must be mapped, so that the systems can be designed with these incremental improvements in mind, keeping, however, compatible interfaces and services across versions. Systems Engineering can contribute greatly to the mapping process, assuring the maintenance not only of software but also of more valuable assets such as information and knowledge, procedures, and infrastructure.

5.9.1. Final Thoughts and Future Directions

Throughout this book, we have reviewed the multifaceted challenges that have arisen or become exacerbated following the exponential traffic growth observed in today's wireless networks. The associated complexities call for advanced as well as simple and incisive network management and control algorithms. We have reviewed various proposed state-of-the-art solutions for managing complexities in next-generation mobile networks. This discussion has provided a global view of the next-generation mobile networks challenges and potential solutions that can help to address these challenges—a view that should serve as a useful guide for students, researchers, and practicing professionals as they consider their engagement with the global mobile networks enterprise.

By all accounts, the complexity in management and network operations of next-generation mobile networks continues to rise. Indeed, most networks continue to be owned and operated by entities that were not part of the core research and development enterprise. In most cases, that domain is not even familiar. This chapter has presented strategies that entail the traffic-based reconsideration of management and control in next-generation mobile networks. These strategies include improvements in network design that are reflective of operator needs and features in light of current network evolution for an efficient path to new service.

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