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Enabling Zero-Touch Operations in Telecom: The Convergence of Agentic AI and Advanced DevOps for OSS/BSS Ecosystems

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Abstract

Zero-touch networks and services design and management have been studied both in academia and industry. This text focuses on the overall operation of the telecom field, especially on operations support systems and business support systems. The traditional telecom OSS/BSS ecosystem has been observed as being too complex and evolving slowly. This has impacted service providers in a variety of business and technological aspects. This text explains the new OSS/BSS ecosystem, its fundamental components, AI's critical role, the need for a new AI paradigm, and its advanced implementation during a service provider's zero-touch OSS/BSS transformation journey. The future of a zero-touch telecom OSS/BSS ecosystem is analyzed. The telecom industry is transitioning to zero-touch network and services across the whole telecom ecosystem including the network operating environment (network operation, deployment, and maintenance);services;business. This text focuses on the first one: zero-touch OSS/BSS, the evolution of the telecom OSS/BSS ecosystem, and the convergence of advanced DevOps and agentic AI. Zero-touch OSS/BSS can automate and orchestrate complex engineering tasks without human intervention. This allows a multitude of technologies and subsystems in the OSS/BSS ecosystem to collaborate in a multi-domain way. This allows for the entire OSS/BSS ecosystem to deliver fully autonomous, intelligent, and high-velocity operation capabilities. Exponential growth of complexity in service providers' OSS/BSS ecosystems (demand for complex and sophisticated capabilities, emergent requirements from multi-partner collaboration, diversifying applications of emerging technologies). Underlying reasons include: Slow evolution leading to technology and system siloed issues; Tendencies of building orchestration-centric OSS/BSS systems. The need for a new OSS/BSS ecosystem (digital transformation requires a paradigm shift). The only viable option is to completely overhaul the OSS/BSS ecosystem: Construction principles (augmented intelligence, DAO, service-centric), and Technical framework (OSS/BSS architecture stack).

Keywords: Agentic AI: Emerging Opportunities for Zero Touch in Telecom - Telecom - OSS/BSS - AI - Observability and explainability - AutoML - Knowledge graph - Advanced DevOps Advanced DevOps for OSS/BSS Ecosystems - Telecom - OSS/BSS - DevOps - Agents - Observability and explainability - AutoML - Knowledge graph.

1. Introduction

Telecom operators worldwide are looking at ways of competing across national borders and across service lines through M&A activity, and through shared infrastructure partnerships with other operators in adjacent service markets. This has and will produce large and complex OSS/BSS ecosystems with sociotechnical systems of applications, many of which may not have been designed to interoperate with each other, and in which the local business processes and workflows may violate the business process assumptions of the original applications. To realize the benefits at this new scale it is clear that the OSS/BSS ecosystems will need to be re-engineered to be more task-centric, more agentic, and more integrated.

Using a reference architecture and functional roadmap, the emerging research and technology landscape in AI and programming is examined to understand how these new technologies can be woven together to achieve autonomous end-to-end workflow and orchestration management of OSS/BSS ecosystems. It is proposed that new generations of AI agents will emerge that will be able to orchestrate heterogeneous OSS/BSS ecosystems, fluidly integrating across proprietary system interfaces to manage knowledge and cash flow. These agents will be composed from components across a hyper-extended technology stack that comprise natural language agents and visual reasoning agents that will reason with textual and visual data providing input to a new generation of generative logic engines built on forward, backward and mixed chaining implementable in standard programming languages. Acts of composition and synthesis will be enabled by new Genetic Programming techniques that build architectures from a library of generative designs through analogy with human artifice. New AI development tools will enable the ideological construction of agentic AI by programming in languages of human cognition rather than conventional programming languages.

Each of these general approaches is already being developed in isolation, but much work remains to weave them together into working systems. As they begin to emerge they will offer new modelling and simulation capabilities far beyond the current state of the art. But equally important, agents of this more general kind will remain a long way off. It is therefore imperative that thought is given to the ethical implications of these developments and how to ensure compliance with safety principles.

Fig 1 : The transformative impact of AI and generative AI on OSS and BSS in telecommunications.

1.1. Background and Significance

Network operators across the globe are focusing on operational transformation strategically while recognizing that considerable investments have been made on the software driven OSS/BSS systems. Networking industry analysts believe that if 40%+ capital savings can be generated from Next Generation OSS operations driven by an AI powered alignment of technology, processes and people, then operator capital efficiencies approaching the 65% observed in the traditional software businesses are attainable. It is championed that a zero-touch transformation could potentially offer significant yearly operational expenditure savings along with reduction in time-to-market and significant improvement in overall customer experience with a design once run anywhere support of zero-touch applications.

Over the next two years, operators should focus on enablers like hybrid infrastructure & automation platforms, agentic AI driven applications, advanced DevOps toolchain, enterprise security and sustainable IT architectures. Development should follow the ability of fully self-contained and self-sufficient modular components to process entire workflows without the necessary involvement by operators/ engineers. Zero-Touch OSS/BSS component orchestration should go down to element management systems or control plane/ core services and model driven working principles must be supported to extract rules on reasonable time frames. Another focus area should be agentic AI capabilities for guidance and remediation assistance of operational processes and situational guidance for engineers. Advanced self-healing capabilities must be introduced into the networks reducing both failure recovery times, and alarm handling load on operations teams by 60%+. Zero walk up, real time remediation support and 100% algorithmic based workflows for routine tasks, 14x faster decision making for complex maintenance analysis and network optimization tasks are expected outcomes from this OPEX focused investment.

A common extended poster architecture must support duality of hybrid multi-cloud and legacy on-prem workload hosting. Standards based multi-cloud abstraction and OSS/CDAP focused unified observability must provide outsight and insights on the hybrid meshes of cloud environments supporting hybrid cloud smart analytics model and raising existing AI assets to new heights. 100% shift of programmable network infrastructure configuration & operational control to automation, no-touch NoOps and on top observability driven decision making hybrid autonomics are potential industry game changers. Current cloud observability platforms and Smart Network Monitoring Systems need to be integrated in a unified hybrid multi-cloud observability platform.

2. Understanding Zero-Touch Operations

Transformative changes in network resilience and sustainability are anticipated as a result of the extensive rollout of 5G and its evolution towards 6G networks. This involves considering larger factors such as climate change, social disparity, and a wider variety of services and applications. Network operations are expected to be automated significantly based on artificial intelligence (AI), leading to zero-touch operations that minimize human intervention. There are two types of zero-touch operations: human-touch autonomous operations in which humans are part of the operation loop, and zero-touch operations in which there is no human-touch portion during execution or decision-making . However, to make these operations work in reality, the current outsourced operations must undergo substantial changes to become zero-touch capable.

Network automation is a process in which autonomous or semi-autonomous scripts or software components make self-executive operations without human intervention. Network operation automation may involve one or more of the following processes: planning, deployment, configuration, detection, diagnosis, testing, and healing. Handled through automation, these processes can become zero-touch operations as there is no human involvement in executing the operations after they are designed. However, the additional processes for zero-touch operations must be developed. By definition, to let something run in a zero-touch manner, it must have the ability to take actions without being operated on, which means that it must contain an additional layer of decision-making or execution processes compared to its automated counterpart. Otherwise, it remains fully manual.

A traditional description of automation is deterministic automation, i.e., given an operating environment or circumstances, the automated method for each possible circumstance is defined explicitly. This requires enormous efforts both to design such automated methods and to maintain them in a dynamic operational environment where input information can change unexpectedly. However, it is impractical to exhaustively capture all possibilities or for AI-based networks to have perfect knowledge of the higher OSI layers. By definition, AI aims to mimic intelligence or enable intelligence by allowing the automated method to complement itself based on the prior or current states of the circumstances.

2.1. Definition and Importance

The term "zero-touch" means contemporary systems or networks should be operated with little or no human supervision and intervention. Such networks or systems are also referred to as fully or highly automated systems. The idea of zero touch is readily applicable to telecom/conventional telco systems: the operations of the telecommunication systems should ideally be controlled, governed, and managed end-to-end automatically with minimum or no human actions whatsoever. A commonly acknowledged understanding is that telecom networks should try to achieve zero touch operations, which requires the aim of minimum human intervention or supervision from either the operators or managed entities . In other words, zero touch operations aim to achieve autonomous and self-governing networks or systems from the perspectives of operations and maintenance. Such systems should be able to monitor themselves, assess the current states, proactively discover possible concerns or problems, plan counteractions, self-reconfigure and self-reoptimize accordingly, and complete those adjustment actions accordingly without being requested or supervised by humans.
Autonomous operation or zero-touch operation is especially important in telecom networks. The advances in many technologies and applications such as the Internet of Things, Big Data, cloud computing, artificial intelligence, edge computing, and augmented reality are inducing a new paradigm of intelligent telecommunication systems with endless opportunities and unprecedented challenges. It is expected that there will be multiple service providers to collaboratively offer computation and storage resources, thus subject to concerns such as heterogeneity, interoperability, multiple ownerships, and different and dynamic data storage, leading to the flattened and more complex telecom service environments and social ecosystems. Automated operation is thus necessary for ensuring the sustainability and scalability of the complex telecom systems. Therefore, the development of fully automated (or zero-touch) operation of conventional telecom operation support systems/business support systems is of timely fundamental importance.

Equ 1 : Operational Efficiency (OE) Equation

$$OE = \frac{(AI_{autonomy} + DevOps_{agility}) \times Process_{automation}}{Manual_{intervention}}$$

2.2. Benefits for Telecom Operators

Telecom operators will significantly benefit from zero-touch activity in their OSS/BSS ecosystems. In addition to resolving the product and customer hand-off pain points for NPNs, ZT-OSS/BSS troubleshooting and mundane operation activities will eliminate time-consuming operator tasks and enable OSSs/BSSs to monitor, analyse, and resolve problems with negligible human involvement. The ZT-OSS/BSS idea is also explored, including the necessary infrastructure, activity types, and architecture. Consequently, the ZT-OSS/BSS concept and its infrastructure could be applicable to a wider range of domains outside the mobile telecom industry.
With the transformation of the telecom industry, more and more communication networks and services are based on cloud computing and AI technologies. AI-enabled network elements, including radio access networks (RAN), core networks, and management components in different functional groups, can collaboratively monitor, analyse, and optimize large-scale telecommunication networks and services from various aspects . This paper proposes the concept of zero-touch operation for all OSS/BSSs to address the existing main technical bottlenecks in adopting widespread AI technologies: incompatibility with existing infrastructures, and inadequate AI features for system behaviour understanding. Essential infrastructure components required to carry out these extensive-scale zero-touch activities in OSSs/BSSs are discussed. Additionally, the types of activities typically carried out in OSSs/BSSs that could be pursued in a zero-touch manner and the architecture needed to implement the zero-touch activities are presented.

2. The Role of OSS/BSS in Telecom

The telecom sector is undergoing profound IT architecture transformation emanating from the virtualization of the telecommunications infrastructure. The paradigm of hardware-centric, 'appliances' or 'medium boxes' for NF and proprietary interfaces is being replaced by 'White Box' compliant with SDN and NFV, open hardware specification and interoperability awareness. The standardization of open APIs is essential to the accruement of the maximum consumer surplus of large investments made in virtualization. COTS IT infrastructure components such as rack-mounted servers, switches, software hypervisors, etc., are expected to leap in their share in the infrastructure of telecom operators (telcos). The transition from the hardware-centric appliance based network to SDN-compatible open infrastructure will trigger the emergence of open-source SDN/NFV solutions. At this scale, existing OSS will become a bottleneck because they will layer on top of the new virtualized infrastructure. Their new generation needs to be built around large-scale orchestration engines, leveraging micro-service, Stateless deployment, runtime instrumentation mindful of the distributive nature of concerned FI, and among others the optimization potential of actor-based programming, quantum readiness and meta-heuristic AI empowered optimization policy engine.
New-age networking paradigms like Network Slicing and IoT will undermine LTE/5G and cloud native application development and deployment. Networks will be expected to automatically and recursively provision the nine orders of magnitude hardened from end-user point of view, and resource utilization mindful of the customer Good-Tux (Cost, SLA Allotment, QoS Expectation, and Fairness eTOM contracts). Non-pliably programmable network synthesis will be triggered by atop termed offense-to-intelligence or top-down policies, and to be managed by service graph and articulation-parameter sensitivity monitoring driven policy flow. This will exert new the convergence of xAI, new DevOps paradigms and theorization frameworks.

Fig 2 : The Crucial Role of OSS/BSS Testing in Telecom Operations.

3.1. Overview of OSS/BSS Systems

OSS and BSS are necessary and foundational components for telecommunications service providers. Operating support systems (OSS) are systems that aid telecommunications service providers in monitoring and controlling their networks and services. Business support systems (BSS) encompass functions for service provisioning, billing, customer interaction, and troubleshooting. OSS/BSS systems have traditionally performed their proper functions in isolation, supplemented by inner components such as mission-specific scripted programs. This has resulted in the operational processes addressing bottleneck problems, incidents and service initial provision taking months. OSS is a group of systems that aid telecommunication service providers with monitoring, deployment of automated controls to, and controlling of their networks and services. In a telecom landscape, OSSs lie between the low-level network layer and the high-level multi-domain orchestration and control layer. OSS comprises systems in charge of network fault management, service fault management, service performance management, service assurance, and service provisioning. BSS systems find themselves at the back office of service provisioning systems, responsible for trouble ticket creation, service provisioning order acknowledgement, and service provisioning monitoring.

OSS/BSS systems are typically developed through the following steps: documentation parsing, knowledge representation capturing data flows and acting patterns, rule processing including generation and deployment of scripts, execution of rules as helper programs for fulfilling OSS/BSS functions. Process mining can be taken as input log parsing plus process representation. On the data representation level, log parsing generates a dataset that describes the workflow of interest. On the workflow representation level, the dataset is transformed to a process model that captures the causality relationships among activities to form a visualization. The two methods of process mining thoroughly expose pre-contained working patterns embedded in a log file by recovering process models. When on top, knowledge representation can predict problems owing to its over-approximation of the success states of a business process.

3.2. Challenges in Current OSS/BSS Implementations

Despite significant efforts and technical advances to develop new use cases and implement modern architectures and frameworks, existing OSS/BSS are under-performing in many areas. In particular, current solutions are unable to address the following five fundamental challenges, which are at the same time opportunities for any solution addressing these challenges.

First, the strong societal and regulatory pressures for near absolute quality-of-service (QoS), security, and privacy in enabling the reliable operations of communication networks with unforgettable societal and commercial consequences. The failure of emergency calls during critical events has put enormous pressure on telecom service providers, infrastructure vendors, and regulatory bodies.

Second, the increasing difficulty and complexity of technology transition in telecom, especially in facilitating the interoperability and evolvability of multiple concurrent technology stacks which are currently in transition from legacy to emerging technology stacks. During this transition, existing proprietary technologies cannot be abruptly replaced because service providers' infrastructures must keep functioning, while on the other hand, technology evolution and standard deployment timelines take several years.

Third, the increasing cost of development and deployment of new operations of telecom services, infrastructures, and networks capable of satisfying specific traffic and latency requirements, especially with over-provisioning to mitigate the uncertainties of input cases and human behavior. Accordingly, a rapidly deployable and standard-compliant OSS architecture must embrace existing technologies, minimize the deployment of NexGen OSS solutions, and maximize the utilization of machine learning and artificial intelligence technologies in facilitating OSS changeability and evolvability.

Fourth, the increasing difficulty of human resources for OSS development and deployment, because a significant portion of OSS knowledge and capabilities were cultivated during decades and often prohibitive cost to be converted to a machine-like form. Such a greater need for field knowledge in developing, enhancing, and operating switch-related services and networks makes a question paramount: how to preserve such a business-critical asset against a potential human resource loss.

Fifth, the increasing aggressiveness of telecommunication companies in enhancing the quality of OSS/BSS operation, especially in the developing world, where competition is increasing rapidly with the growth of technologies. In contrast, OSS/BSS solution vendors are taking a more conservatives position in fighting for customers on the reluctant to moving away from their existing suppliers and co-deployed solutions.

4. Agentic AI: A Game Changer

Agentic AI is the highest level of Artificial Intelligence (AI) functionality. At its most basic level, agentic AI consists of intelligent agents that are autonomous, goal-directed and able to migrate between problem-solving environments. Indeed, agentic AI is capable of taking non-linear paths through complex environments enabling surprising bursts of creativity and productivity in its pursuits. More advanced agentic AI incorporates a variety of cognitive capabilities supporting self-knowledge, metareasoning, persistence, argumentation, belief revision, and sociality. At even higher levels, agentic AI draws upon creativity and commonsense reasoning, requiring the convergence of disciplines that haven't yet converged—evolving consciousness and C-Strings. Agentic AI has caused significant changes across a wide variety of industries and academic institutions. Recent blue-sky outlooks predict a thorough transformation of the global economy and society within a few short years. Academics, journalists, business leaders and government officials, alike, have framed agentic AI as potentially the greatest existential management dilemma since the advent of nuclear weaponry. Any society, organization, or individual that does not or cannot adapt, operate, and compete with agentic AI will fall woefully behind . In response, there are calls for a legally binding international treaty to ban and control the deployment of agentic AI comparable to the Montreal Protocol, Nuclear Non-Proliferation Treaty and the prohibitions on biological and chemical weapons. Research is also urgently needed to understand the development of agentic AI algorithms, motivations, strategies, and unintended consequences, such as fraud, disinformation, radicalization, propaganda, manipulation, and escalation of cyberwarfare. The emergence of agentic AI invokes questions not only of what is possible, but also of what will be. Longtermist and existential risk perspectives frame the prime question as "What is to be done?"—aiming to steer development in a positive direction and to minimize risks of catastrophic outcomes.

In response to these concerns the denizens of the OSS/BSS ecosystem aspire to work with agentic AI to design, develop, and train it. Education is a priority—co-development of an initial curriculum or coursework to bridge the researcher-practitioner divide. Workshops and retreats are sought to discuss understanding of agentic AI development along with its potential management dilemmas, risks, and hypothesized designs for cooperation. Design competitions for best agentic AI use-cases and/or agentic AI-human collaborations are also desired to crowd-source a variety of perspectives and approaches. Ultimately understanding agentic AI will require developing agentic AI itself. In response to these proposals, four social scientists within the OSS/BSS ecosystem reached an agreement to collectively explore the coordination of the various efforts.

4.1. Defining Agentic AI

Intelligent systems traditionally consist of fully automated AI agents coupled with a human operator who is solely responsible for monitoring the overall performance, intervening when necessary, and fixing faulty modules. In this design, the switched-on operator acts as the last line of defense, able to terminate an ongoing setup. An agentic AI ecosystem extends state-of-the-art intelligent systems such that agents possess full autonomy, that is, so that an agent could take the place of the traditional human operator. These agents can organize into multi-agent systems (MAS) through the well-studied paradigms of coordination and cooperation.

Intelligent systems with automated software agents that work in automatic, proactive, and autonomous ways are colluded with agentic AI. Here, intelligent software agents can act collaboratively situated in a multi-agent system (MAS) that performs tasks on behalf of their customers. Agentic AI goes beyond conventional intelligent systems, since both the system performance and the system structure are continuously adapted and optimized through the teamwork of all agents in the agentic AI ecosystem . It is contacted with high demand services requiring massive resources or knowledge exchange. AI agents deploy an intelligent system in a zero-touch way, where no human intervention is suitable for problem handling.

Agentic systems are subject to strict fundamental assumptions: public observability, certainty, and benevolence. When the knowledge efficiency relation of an agentic network gradually diminishes, while still positive, agentic systems might be better resilient to any of these controller (vote) attacks than the optimal reputation-based mechanism . An agentic AI ecosystem consists of hierarchically organized intelligent agents (IA) that observe and act on a designed pool of monitoring models (policy, planning, learning and data). Fully automatic agentic AI systems are designated to immediately act on anomalous observations to keep the monitoring models updated and avoid plan reconstruction due to damage from attack.

Equ 2 : Service Reliability (SR) Equation

$$SR = \frac{Predictive_{AI} \times CI/CD_{velocity}}{Incident_{frequency}}$$

4.2. Applications in Telecom

In the past years, numerous Telecom backbone and service networks, systems and software have been architectured and developed, deployed and evolved, which are essential for creating, delivering and consuming various communication and information services between human users and machine entities . Such personnel, organizational, operational, and technical facilities can collectively be termed Operation Support Systems and Business Support Systems (OSS/BSS). OSS/BSS is recognized as the backbone support for Softwarized, Cloud-native, and Zero-touch Networks (SCZNs), playing key and fundamental roles from telecom service strategy and policy planning, to deployment blueprint and execution, as well as all-in-one operational management and global telemetry observation.

OSS/BSS also faces great challenges in the design, architecting, building, and operation aspects in the perspective of SCZNs. Enabling SCZNs requires a radical transformation for OSS/BSS, from a traditional telecommunication industry perspective, and from both a practical engineering and a research perspective. Regarding the telecommunication industrial perspective, there is a heavy burden of legacy systems, along with complicated architecture, heterogeneous resources and cross-generational software. Modes of operations vary greatly from operator to operator due to different OEM suppliers, evolutions, and individual acquisitions in history. State-of-the-art evolution has been carried out step by step in ad-hoc manner, resulting in ad-hoc systems, siloed data islands, and no "big picture" for the networks and services. Collaborations and cross-makings between systems software, tools, and data with business scenarios are difficult. As a result, a huge room is left for improving the overall operation efficiency, resiliency, and innovation-ability.

OSS/BSS systems are facing great operational challenges to cope with the ultra-rich and dynamic network service demand changes, with an overall increasing service scale and complexity, a cloudification drive for enhanced scalability and flexibility, and increased competition and disruption in the market. OSS/BSS systems are also eager to evolve towards a "central brain" horizon to support a gradual and seamless business model migration, operational procedure automation, and digitalization, along with key enablers such as intelligence orchestration, knowledge-driven management, active learning, and holistic telescopic observation.

4.3. Impact on Operational Efficiency

When addressing service operations in typical 4G/5G networks, OPEX burdens across Individual Operations, Service Operations, and Transport Services are investigated. Service outages influence the overall network performance. Major OPEX contributors to the operational hierarchy in standard operations, service operations, transport service operations, and individual operations of processing, transport, and connection paths are mapped. In addition, service impact models are introduced to quantify the influence of service outages on OPEX. A method is established to identify single points of failure given network structure that allows for hidden soft failures. This includes unexpected/unpredictable OPEX costs due to human errors. On a macro-scale, this analysis is performed considering realistic scenarios of 4G/5G deployment cases. Observable OPEX improvements are proposed and discussed, focusing on operational procedural changes and retrofitting the existing operations to a more automated autonomy state. Human fallback structures are included to the analysis to improve the feasibility and acceptance of transitioning with respect to legacy operations. With respect to the structured approach in identifying OPEX impacts based on Hallmark SNMP MIB, worst-case impact scenarios and OPEX improvements are presented. While developing this analysis, the robustness of some methods is put to the test. Additionally, suggestions for further work are proposed in order to narrow the scope of the impact quantification. Following the analysis of the worst-case incidents and largest OPEX contributors, the MANTIS project aims to maximize the operations and maintenance efficiency on these challenging areas. This includes transitioning into an AI-aided automation of the operations and presenting automated solutions. The main aim is to progress towards the levelling of the operational maturity of the 4G and 5G elements across the EU.

5. Advanced DevOps Practices

Telecommunication networks have been going through a massive overhaul and upgrade to become cloudified and virtualized. More specifically, application-agnostic hardware is nowadays preferred over proprietary box solutions and virtualization technologies are applied to have decoupled function implementation and fulfillment. As a further step towards programmability and flexibility, network functions written as microservices and arranged in complicated topologies communicating over underlying standard interfaces are the next step to take. Microservices are lightweight solutions that are easier to evaluate, develop, and maintain. It is much cheaper and easier to deploy new features and to perform experimental upgrades. Moreover, the elasticity of microservices gives the opportunity to reallocate network functions depending on load and other parameters, thus leading to cost-efficient and low-priced services to customers. To leverage the multitude of benefits brought by microservices, using languages and architectures that de facto became industry standards is vital. Those are Open-RAN, O-RAN software, and orchestration with Kubernetes. As DevOps is the industry standard to make code deployment, update, and testing easier, standards and guidelines must be derived to move OSS and BSS code from their century-long situation without virtualization and fast execution to software-based ones that can eliminate almost all manual operations and make things potentially run fully autonomous and thus zero-touch.

DevOps is a general term that refers to the homogenization and automation of code build, deployment, and verification on the infrastructure it runs on. DevOps teams provide flexibility to the development and QA teams to continue testing and developing on pre-production replicas of an inline environment. For OSS/BSS specifically, DevOps processes rely much on cloud infrastructure and coding capabilities. Revolutionizing OSS/BSS for the digital services economy. Manual intervention of processes and validation of performance is being phased out and an entirely automated system able to run on a predefined cluster of machines is emerging as a goal. The last step is to have software for an end-to-end OSS/BSS that would be able to handle errors on-the-fly, thus enabling fully autonomous zero-touch operation at a strategic corporate level .

5.1. Overview of DevOps in Telecom

The concept of DevOps (Development and Operations) is rooted in agile software engineering, yet its successful implementation in telecommunications lies beyond simply installing a toolset. Fundamental changes to the organization and culture of all stakeholders involved in telecommunications assurance and service orchestration are required. High-level recommendations for implementing DevOps for assurance tasks in virtualized, carrier-grade networks are provided, leveraging ideas and designs from a collaboration with a leading global telecommunications provider. In the telecommunications industry, the operational practices of managing and controlling core networks and service delivery points still predominantly employ monolithic, closed, proprietary, vendor-specific, and obsolescent systems. These neolithic OSS/BSS systems are not able to keep pace with switched service speeds in the 100Gs, with the pace of new applications becoming available, or with the complexity arising from its SDN-based service innovation.

The building blocks of controllable, manageable, operated, and monitored systems bundled as IT-controlled and operated end-to-end services are described first. Only when such systems are in place can assurance systems be flexibly assembled and adjusted to use cases and scaled to nontrivial sizes. Assurance systems are thus constructed as collections of service components that instantiate such systems. Examples of (cloud-based) measurement, data analytics, and data visualization systems at network, domain, and transport levels are provided. Thereafter, assurance awareness, a new scope of application for OSS/BSS, is presented, it is able to effectively cope with big data streamed in real-time and batch from tens of thousands of devices/processes. Examples of such assurance systems currently in active use are analyzed, including a leading global telecommunications operator with production-grade assurance and control systems for switched next-generation telecommunications networks.

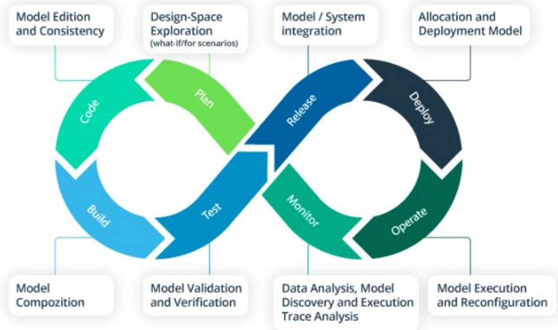

Fig 3 : DevOps in Telecom.

5.2. Integrating AI with DevOps

It is determined that the integration of agentic AI and DevOps poses various challenges, necessitating collaborative efforts by diverse stakeholders to explore suitable solutions.

5.2.1. Challenges and Opportunities

The integration of innovation and DevOps in OSS/BSS systems faces challenges during the ongoing transition toward cloud-native deployment, data governance, compliance, and security. Ownership complexities arise due to the proprietary nature of AI models, while design and development issues emerge from the focus on training rather than testing. Adoption challenges stem from a lack of knowledge, culture, and skills, along with limited support from standards and regulations. Integration difficulties arise from issues related to disparate infrastructures, multiple tools, and inadequate skills. Finally, there are trust issues surrounding accessibility, reliability, safety, and security.

5.2.2. Strategies

Establishing collaboration among stakeholders to carry out comprehensive explorative studies is crucial in responding to the above mentioned challenges. Strategic multi-party workshops or round-table discussions should be organized among academia, industry, open communities, and framework developers to discuss opportunities, challenges, research directions, or policies in adopting AI in OSS/BSS ecosystems. These collaborative activities will facilitate the identification of best practices and agentic AI-enabled DevOps falling within the adoption continuum, from templates and help to phobia. Simple systems and agents to demonstrate the concept will also be required. An industry-oriented advisory group should help shape scenarios and organize demonstrations in collaboration with open communities. Open-source frameworks and reference implementations should be developed to evaluate methodologies and algorithms. Besides, studies on national policies to foster AI innovation collaboration are needed.

5.3. Continuous Integration and Delivery

The complexity of the application stack in Radio Access Networks (RAN) use cases requests orchestration at different granularity levels. In this context, each level of the stack can be seen as a different building block. Building blocks containing logical network functions need to be connected with the physical network service providing connectivity in a manner compatible with the service requirements; for example, the slice imposed requirements. To guarantee that slices are instantiated correctly and with safety measures adopted, RAN slices are characterized at the modelling level by a service model defined by the service level agreement (SLA) and monitoring parameters that describe RAN monitoring at the KPI level and their logical connection with the service level. Therefore, the package containing the agent-level building blocks to be deployed for a RAN slice must be transformed and interpreted independently according to the orchestration level. These packages can be efficiently transported with technologies such as the Open Source MANO Project and its deployable Network Service Descriptors (NSDs) at the network service (NS) level. The deployment contents of NSDs decrease with the abstraction improvement of orchestration level. In this context, the generic difference in the deployment of building blocks belonging to upper orchestration levels is explained, including NSs containing virtualized network functions (VNFs) level, network services with a TN element level, legacy radio devices (RDS) level, traffic steering at the controller level with necessary traffic flow evidence. The general discussion gives an overview of the state of the practice in the DevOps domain concerning service deployment. On the one hand, this service can be seen as the necessary middleware to commodify services delivered by numerous software packages. On the other hand, several restrictions impose limits on the extent of automation in the deployment service. One of the issues specific to the analysis at the core level is the lack of a standardized description language equivalent to the description languages adopted when dealing with services characterized by horizontal emulation.

6. Convergence of Agentic AI and DevOps

5G and 6G systems will further complicate OSS/BSS ecosystems as telecom companies will not own the networks anymore. Electronic Marketplaces (EMPs) will emerge instead, dramatically changing the OSS/BSS landscape. On the one hand, cloud-native 5G and 6G systems provide opportunities to enhance orchestration in OSS/BSS ecosystems and open new channels for zero-touch operations. On the other hand, semantically rich and interconnected OSS/BSS ecosystems incur complexity. Zero-touch operations in telecom depend on the intelligent orchestration module that captures the advanced technological trends and addresses the increasing complexity. This advanced orchestration module may introduce agentic AI to the OSS/BSS ecosystem, which automatically plans, executes, monitors, and refines actions to achieve the organization's goals. Upon successfully establishing this agentic AI-driven OSS/BSS ecosystem, low-code/no-code development, ongoing optimization, diagnosis, and reusability can be achieved with little or no human intervention. The self-* abilities of the OSS/BSS ecosystem can also be further explored and implemented, including predictive maintenance, automated troubleshooting, and self-updating under the paradigm of advanced agentic AI in real future implementations.

In the literature, there are increasing focuses on agentic and distributed AI systems in telecommunication, cloud networks, datacenter networks, and smart cities. These works proposed many promising intelligence-driven orchestration mechanisms. Despite these significant works, there is a gap in promoting both agentic AI's fast and accurate deployment and continuous co-evolution with existing OSS/BSS architectures. Telecom-grade OSS/BSS systems are too complex and heterogeneous to be replaced but instead have to be asynchronously transformed. It means agentic AI training and refinement should happen at a single agent concurrently with the OSS/BSS ecosystem's continued evolution . To bridge this gap, it is necessary and important to make the OSS/BSS architecture less complex (characterization) and easier to adapt/change, which depends on suitable abstraction (homogenization) and a suitable information-driven orchestration mechanism.

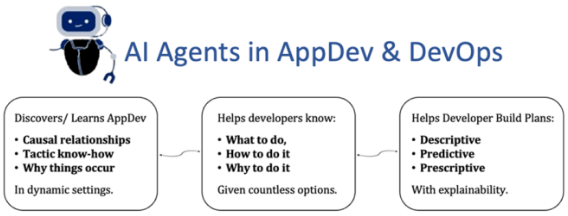

Fig 4 : The Agentic AI Revolution in AppDev and DevOps.

6.1. Synergies Between AI and DevOps

Telecom networks today mainly comprise hardware-based, closed vendor products, which are expensive to maintain and expand, are oriented towards a single vendor, and do not provide long-term scalability options. Network data is locked into silos and is often poor quality, making it hard to leverage AI/ML applications to facilitate automation. Siloed OSS/BSS systems do not interact with each other effectively leading to automation within one sub network or silo but requiring manual touch for more complex transactions across OSS/BSS systems. Mistakes, inefficiencies, and unwanted service disruptions are highly probable for actions requiring multiple systems to interact. There are growing cyber risks as networks and systems become increasingly open and programmable, while poor quality of data and legacy systems stores still linger. As networks get bigger, these manual processes lead to a dramatic increase in operational costs and time, which in turn leads to difficulties in human resource management for tackling complicated tasks.

Blending the tenets of DevOps with agentic artificial intelligence ensures the seamless operation of mission-critical OSS/BSS ecosystems with minimum human intervention. In particular, modern agentic AI are infused with agents capable of independently orchestrating a number of long-running steps using off-the-shelf tools with language instructions. Early enterprise case studies seeing first returns of 3-5x productivity uplift have emerged predominantly on non-realtime and non-mission critical tasks. In particular, agents orchestrating real-world tools, e.g. Cloud resource provisioning or ticket tracking in ITSM systems, are among the earliest to watch. Two factors are contributing to this buoyant outlook.

On the one hand, tool usage likelihood models to learn when a tool is needed are developed. Only those tools expected to have high utility will be hooked to an agent/invoked to execute a plan. On the other hand, task definition languages to characterize the task type of a user query are devised. Only those languages expected to be aligned with the user query will be used by the agent to execute a plan. By injecting heterogeneity into agents' tool and language sets, united tooling nodes may be further enriched with new models to functionalize requests across a family. The same methodology may be applied to inject traditional AI techniques to further enrich the payload channels of producers and range arbitrary device interactions.

6.2. Case Studies of Successful Implementations

The world of public communication networks is undergoing a massive revolution. Currently, these networks offer relatively static services, governed by vast, complex flow charts of conditions and actions, constructed by a large team of highly trained engineers. This world will undergo a critical paradigm shift, where the majority of the conditions-action pairs will be learned and continuously evolved via Machine Learning/Artificial Intelligence (ML/AI) trained on historical treatment flows of a service network comprising dozens of hybrid geolocalized service enhancers. Due to the very large volume of data and the complexity and dynamism of state variables (such as time, service parameters, and their categories) and actions (which include a large set of possible actions, with quite a few inputs defining a unique action), processing this data cannot be stored in a single homogeneous frame but rather will be distributed in a hierarchy of semi-autonomous and federated ML-based modules. Models and optimized decisions will thus need to be seamlessly fed across the hierarchy to implement the foreseen technical vision of a hybrid network with autonomous services and zero-touch operations.

First, the general architecture and key challenges for the 6G Zero-Touch BROadband Internet-of-Things networks (ZBROAD IoT), will be presented. Subsequently, the reference architecture for Deep Learning-as-a-Service (DLaaS) based broadband access IoT networks, to accommodate federated and collaborative l-Edge intelligence, learn and treat burst events while guaranteeing promised quality of service, based on continuously trained hierarchical AE, will be discussed. Last but not least, potential standardization needs and approaches will be outlined, focusing on the ITU-T X.6XX recommendation family and in particular on a set of candidate working items (WIs).

The epoch-making COVID19 pandemic has imposed an unprecedented quantification of the impact of the Internet of Things (IoT). A vision of a hybrid world of interconnected and collaborating intelligent agents and developments of an altogether new architecture with unprecedented security of the worldwide IoT have been implemented to accommodate this immense growth and establish the Zero-Touch BROadband Internet-of-Things networks (ZBROAD IoT), as a paradigm-shifting revolution in the management of public communication networks. An end-to-end architecture, comprised of LightFields, ML Edge processors, a Hybrid Soft-Switching Service Network based on elastic nonlinear photonic lattice solitons, a federated Multilayer 4D Space-Time processing with Soft-Optical Network-on-Chip fabric has been proposed.

Additionally, a comprehensive ML structure has been defined, consisting of a theoretical framework for expressible ML in the hybrid network, the classification of all forms of multi-modal Controllable Generative Latent Process (CGLP), the structure of shallow models encompassing deep Belief Networks, graphical- and generative-controllable CGLP autonomous intelligence modules, and the reference architecture and protocols for generative intelligence as a service in the ZBROAD IoT. Finally, the technical need of an Information Architecture (IA) to complement the E2E architecture via ontological modeling databases has been outlined together with potential standards decomposition and mapping approaches. Thus, the current state of the System Zero (S0) side is that zero-touches have been moved, but zero touches have not yet been hired.

Equ 3 : Time to Resolution (TTR) Reduction Equation

$$TTR = \frac{1}{AgenticAI_{proactivity} + Observability_{depth}}$$

7. Implementation Strategies for Zero-Touch Operations

Today's intelligent and global telecom services call for advanced operation support systems (OSS) and business support systems (BSS) that will automate the various functions across the OSS/BSS streams. Intelligent automation requires an evolution in telecom OSS/BSS systems and lends to integrated AI to discover, reason, plan, act, and learn in support of zero-touch operation (ZTO) services and systems. The core of OSS/BSS signified as the telecommunication operational system lies in an increasingly complex and dynamic multi-tenant architecture for digital operational data. The diversified, increasing, and growing services pose open challenges in massively scaled up service runtime analytics. Telecom influences and delivers software and data-powered services into the industries and society with an unprecedented volume, velocity, and variety. Recent advancements in linguistically grounded text-to-text based natural language operations empower the analysis and understanding of a diversified, unstructured, and raw operational service runtime data. It, as a powerful foundation model, also serves as a platform to build domain-centric OSS/BSS applications. Advanced AI, as a technology foundation, and ML/NLP-augmented OSS/BSS applications, as an AI solution and evidence to algorithms, together cause and demonstrate the complexity, scalability, and evolution of a digital operational system in support of operations case, use, and service excellence. ZTO solutions on data and operational best practices open up new grounds on OSS/BSS evolvability, extensibility, and adaptability in cloud and cloud-native environments. A digital operable O/D/B system makes an OSS/BSS more intelligent and autonomic with the risk and cost reduced and benefits expedited through AI-driven data-centric operations. They hold a potential opportunity to operate a growing, complex, and evolving OSS/BSS with a digital operational footprint that makes insights and best practices explicable, interpretable, and scalable.

Fig 5 : Strategies for Zero-Touch Operations.

7.1. Framework for Implementation

The advent of 5G has evolved into a significant business opportunity for telecom domain players due to the opening of large and heterogeneous service horizons. However, the substantial operational costs amid low profit margins have posed considerable challenges for operations teams. Consequently, the necessity for business and telecom network operators to adopt zero-touch operations—enforcing smart, autonomous, and self-sufficient OSS/BSS (operations support systems/business support systems)—has emerged as crucial in the evolving telecommunication constellations. Justifying the existence of networks (and hence, OSS/BSS systems of networks) has been limited to the questions concerning how well–in terms of performance, throughput, latency, and coverage, among others—service orchestration solutions answer the demands placed by service requests. It must, however, start evolving into a question of why to have such networks or service orchestration solutions (and, hence, OSS/BSS systems). It must be understood and clarified under what contexts or in what conditions the proactive establishment and maintenance of resources would lead to the de-facto optimization of resource allocation, satisfying both the service quality parameters of the services offered and the billing mechanisms of the operators.

Valuing telecom ecosystems as complex socio-technical systems calls for a local-to-global (and hence, in reverse, a feedback global-to-local) approach to end the complex pricing/revenue allocation and service orchestration/maintenance/exploration problems, involving the service resilience and quality freshness/updating. The very structure and performance aligning algorithms of these OSS/BSS systems would need to change radically, thereby affecting all telecom players in the ecosystems. Adopting global-pricing, eco-feedback-, and exploration-based pricing would lead to valuation of network infrastructure in the minds of service providers. Such valuation of the network would drastically reduce frictions in network sharing. The convergence of agentic AI and advanced DevOps would enable telecom players to gain and appreciate a globally-optimal service chain orchestration and maintenance solution, based on local-to-global reasoning in the system's state or distribution of local reasoning. Self-adaptive, trustworthy, efficient, resource-aware, and resilient OSS/BSS ecosystems would, hence, evolve. The key challenges in enabling zero-touch operations in the telecom environment, and more generally telecom OSS/BSS, infrastructures have been discussed.

7.2. Key Technologies and Tools

The implementation of Zero-Touch Network Operations (ZTNO) represents a need for telecom operators worldwide to alleviate their long-standing struggles with rising operational costs, service assurance, and time-to-market. ZNO is anticipated to enable intended Service Level Agreements (SLA) as proactively and autonomously as possible with minimal human effort. However, the open-loop telecommunication networks which telecom operators are currently running would not be able to directly implement ZTNO. Based on extensive literature review, a roadmap for enabling ZNO is proposed, and directions for future research in this area are discussed.

In ZNO, intelligent agents autonomously provide their observations of the access network (including the Radio Access Network (RAN)) and/or core network (comprising the Transport Network, Core Network, and Cloud Network), and express intents (not just specific configurations) to the system orchestrator (not a centralized controller). The intent coherence policy of the agents might be fully default, heuristic, knowledge-based, or learning-based. The system orchestrator sits at the cross-section of Human-Computer Interaction (HCI) and Human-Agent Collaboration (HAC). It consists of interactive dialogs with the human operators, which could be in natural language, visual representation, or any other form suitable for the tasks to be performed. The human views a high-level dashboard of the system for status monitoring. The interactions are entirely non-intrusive, transparent, trustworthy, and sociable efforts.

As one far-reaching step towards ZT NO ecosystems in zero-touch operation of the telecommunications networks, ZT NO EcoSys, architecture entities, and key technologies are proposed in the analysis. The ZTNO-enabled Distributed Agentic AI (DAA), Autonomous Agent as a Service (AAaaS), and Distributed Human-Centric Multi-Modal Data Interaction Technology (DMMDIT) are discussed in detail. Industry-standardization is also recommended as a straightforward means toward implementation of DAaaS-ZNO on top of existing NaaS networks including ETSI Open Source MANO and ONAP.

Examples and ramifications are illustrated to show its implications on privacy-oriented architectures, competition for tool providers, and more broadly adoption of DAA in non-telecom industries.

7.3. Change Management Considerations

While the zero-touch paradigm results in the delegation of most operations tasks to automated processes, there remains a need for oversight including verification, auditing, and recovery. In the case of failure, accountability is often a challenge for automated processes, which are either built on fictitious terms and basic programming or lack awareness of the effects of their decisions through preparatory reasoning. Without proper accountability, it is impossible to implement trustworthiness. Hence, supervisory processes are crucial for proper accountability of zero-touch processes. The reasoning underlying these verification processes should include careful uncertainty handling, as operation processes would rely on imitation of human debugging and correction techniques such as analyzing evidence, hypothesis generation, goal-oriented active testing, and omission of unnecessary conditions. Therefore, sufficient AI capabilities capable of reconfiguring models of the operations task environment need to be integrated into the automated operations processes.

Arguably, a generic hierarchy of design and operation with its various derivatives forms the essential structure in any complex real-world operation task or system composed of subsystems. Likewise, while there remains a vast number of details and possibilities, path-assigning and path-switching techniques form an effectively unbounded library of essential techniques in themselves. Moreover, the extreme high speeds and the accompanying complexity of modern telecommunications give rise to numerous unforeseen difficulties and edge-events.

In a zero-touch system, the application of these techniques in operations, even augmented with AI capabilities, requires oversight by supervisory processes. Classical, mostly traditional, supervisory processes assume a very low automation level and base their reasoning on the scrutiny of the descriptions of the executed commands and checks embedded in the automated operations processes. These can exhibit knowledge, inference, information, and execution and may handle uncertain descriptions. The reasoning involved in these processes primarily includes assumption retrieval and contextual relevance assessment.

8. Conclusion

The majority of the human-controlled tasks will be torchwise taken over by machines in the near future. Telecom and IT operators will leap into the ZTO era. Cloud-edge-computing will be critical to the whole process. A decision nexus exploiting multi-agent decentralized machine learning could lead to the intersection of zonally efficient self-ai telecommunication evolution. ZTO is expected to significantly reduce the need for human involvement in undertaking complex engineering-level telecommunication operations. ZTO is also anticipated to provide telecom and IT operators with a great opportunity to shift from CAPEX- to OPEX-based business models. Nevertheless, this paradigm-shifted evolution has great technical challenges in ICT architectures, protocols, and algorithms. This presents a high-level architecture blueprint for creating a ZTO ecosystem and emphasizes its need for collective-acquirement & wisdom purely AI decision agents. In a comprehensive review, the potential immediate sub convergence fields with the above technologies within the AI telecommunication ZTO ecosystem are pointed out. Numerous potential technical challenges are raised, and the immense research, engineering, and societal efforts expected to overcome these challenges are discussed.

The emergence and evolution of the Internet and telecommunication industries have profoundly changed human societies by bridging the physical and digital worlds together. Nevertheless, the telecommunication and IT industries are at the verge of an unprecedented paradigm shift from human-in-the-loop operations to fully autonomous ZTO. The groundwork for building the emerging ZTO ecosystem has been co-created by the sub convergence of many disciplines of information and telecommunication technologies in the past decade. Many novel enabling technologies have already been invented, including but not limited to AI, brain-inspired computing, wireless sensing and communications, aerial-terrestrial-satellite converged networks, DevOps, cloud-edge-computing, and software-defined everything.

8.1. Future Trends

Disruptive innovations are redefined in the background of the 5G, concerned by the combination of observation, insight, and prediction. The zero-touch autonomy enables further optimization on network operations, as well as the service delivery, encompassing an otal convergence of business-driven AI, data, and capabilities. To this end, a novel entity of thinking agencies is elaborated for the OSS/BSS ecosystems, with a co-evolutionary approach on the overall functional architecture. The agent-based service delivery and DevOps autonomy menace a new regime on operations and revenue assurance, leading to new slicing of network and resource shapes, along with the transformation of technology trends. Nevertheless, agentic evolution is a complex approach where the perception, mind, and embodied characteristics of each agency is interesting to explore and develop further innovations on the agent modeling and induction methodologies. Extensive experiments of the multi-agent operations on diverse OSS/BSS environments are also enthused for developments on richer autonomy intelligence and input dimensionality. Further applications of agentic AI are anticipated in other domains for the hybrid digital-physical orchestration on deep solutions and services.

Overall, this text introduced a new type of OpEx Redefined, focused on the synthesis usage of advanced AI agential technology and advanced OSS/BSS DevOps practices to enable zero-touch operations on the Telecom and Telco Edge ecosystems. Zero-touch is expected to disrupt every single process in the OSS/BSS ecosystem, and the acquisitions of cognitive and sentient ability by OSS/BSS processes make it innovative but also add chain complexity on the design-space of a proper intelligent engine and their respective strategy.

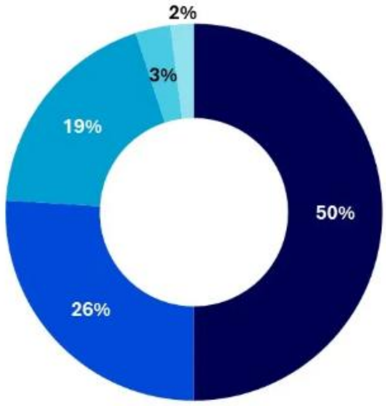

Fig 6: zero-touch operations in telecom.

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