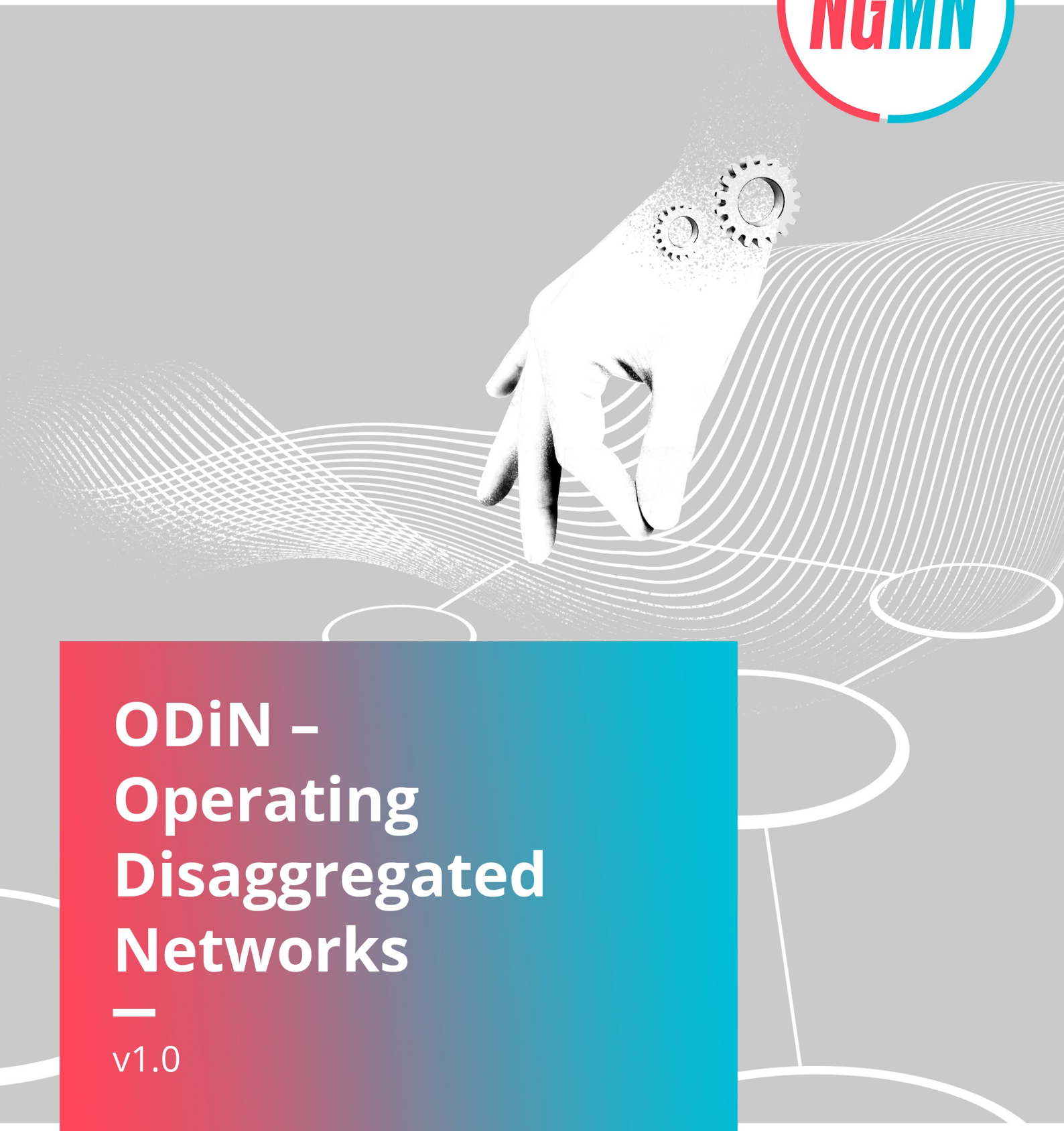

ODiN – Operating Disaggregated Networks

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Abstract

Disaggregation is one of the mobile telecommunication industry's biggest opportunities and biggest challenges at the same time.

The opportunities coming with Network Disaggregation are appealing: a healthier and more resilient ecosystem and supply chain, lower barriers to enter for new player, enabled increased competition and innovation, agility and flexibility.

However, it comes along with a number of new challenges, which particularly the operators, along with their suppliers, need to address. Certainly, it demands a new way of working, most likely significant additional integration efforts, changes in the operational model to embrace new processes, skills and tools. All such efforts are required to eventually ensure the expected service levels, operational efficiency, performance, resilience and security, plus the opportunities to offer new and affordable services, meeting user demand.
Whether the benefit of lowering the TCO (Total Cost of Ownership) can be achieved for operators, is yet to be proven.

Each individual operator will need to eventually make its choices, depending on its strategy, its starting point – greenfield or brownfield, its geolocation, local competition etc. However, there are many topics which need to be analysed and solved, which are possible and worth being solved jointly in the pre-competitive area, to support global standards, economies of scale and hence to enable competition.

"Mastering the Route to Disaggregation" is one of NGMN's strategic focus topics. This deliverable is the first publication of NGMN's "Operating Disaggregated Networks – ODiN" project, representing a first operator view on Disaggregation opportunities and challenges, with a focus on the E2E operating model.
In the next step, the project will invite the entire NGMN Partnership - vendors, system integrators and other interested parties to jointly work on industry solutions to the identified challenges. The project will also work with other relevant organisations, analyse potential gaps and submit requirements to the industry.
One of ODiN project's objectives is the development of blueprints, enabling operators to make their individual choices.

Contents

1 BACKGROUND AND INTRODUCTION

1.1 A New Operating Model

Mobile network operators have optimized their way of work over the past years, ensuring consistency of several criteria when planning, deploying and running their networks. Criteria such as ease of integration, performance, capacity, security and resilience have been used, in the first place to allow not only best customer experience but also proven processes and procedures that cope with the multiple technology vendors and generations involved.

Digital Transformation observed in several domains and areas (e.g. automated industries, market and societal needs, environment, etc.) has driven technologies such as 5G to provide solutions to cope with a vast number of growing use cases with wide range of requirements, increased levels of agility, flexibility, scalability, as well as responsiveness and cost / energy efficiency. In fact, this not only applies to the technology itself, but to teams, processes, and growing partnerships in a broad ecosystem. Ultimately, this digitization points to a great deal of prospects but not without complexities and risks in the absence of insights, tools, operating models, and end to end alignment.

In parallel, Digital Transformation has made huge changes in the mainstream IT platforms with movement to cloud-based technologies (including on-premise and hybrid). This has resulted in:

- Separation of functions from underlying hardware; cloudification, and orchestration of containerized functions
- Service-based architecture, stateless functions, exposure, discovery and consumption of capabilities
- Separation of monolithic services into granular micro-services with open APIs
- Flexible and agile DevOps teams, processes and technologies, and continuous integration and delivery (CI/CD); open-source automation and orchestration platforms
- Open, interoperable and multi-vendor interfaces, and granular components in a broad ecosystem

Network operators are following the general trends in IT. However, there are areas that are specific to communications networks that are not relevant to the more general Digital Transformation of processes and systems. Expectations of reliability, resiliency, speed, and low latency are very different for telecommunications networks.

As a response to the above-mentioned transformation factors and challenges, the industry has driven network disaggregated solutions. As these solutions mature and become increasingly

competitive versus the established monolithic integrated ones, operators start to incorporate them in their portfolio. However, this adoption (one can even say transition) of new network capabilities presents several challenges to the established ways of working. Are operators able to use those capabilities without jeopardizing their quality of service and operational excellence while at the same time remain or become even more cost effective? Is there a need to adapt the current operating model and how can they decide what, how and when to do it?

1.2 Network Disaggregation - the Transformation Catalyst

Network Disaggregation can be seen as both a consequence of the Digital Transformation as well as an accelerator of that journey, and it can be observed broadly from two perspectives:

- vertical disaggregation, where network functions decouple software from hardware, allowing multiple combinations to be used
- horizontal disaggregation, where established network functions are decomposed into more granular elements and new interfaces are designed and specified

Ultimately, this creates more players, able to develop specific components of the overall architecture, broadening the ecosystem, leading to an acceleration of innovation, better solutions and more cost-effective ones.

As a consequence, networks are expected to become increasingly agile, flexible, and responsive. All of these factors provide the means to deliver new communication services tailored to the user needs. This leads not only to new business opportunities but also many different services which need to be managed and operated. Considering that those services are based on a multi-vendor ecosystem and on new self-caring technologies, it is evident that there is huge impact on operations. This in broad sense involves people, processes, technologies and the ecosystem.

Disaggregation enables this end-to-end, particularly through openness, cloudification and softwarization, providing similar impacts as described above for IT, as well as specific NT features such as:

- Separation of control and user plane, programmability and software-defined networking, including SD-RAN
- Flexibility of the user-plane function, hybrid cloud and edge
- System flexibility, composable core, granular QoS architecture, multiple-access
- Network slicing

As mentioned above, these lead to potentially significant benefits to performance, user experience, business perspectives, which will be further detailed in the next document version. These also lead to the necessity to define and adopt a new operating model, as the deployment and leverage of such capabilities is deeply intertwined with the way operators are able to control and exploit them.

NGMN has identified this work as one of its strategic imperatives for 2021 and beyond and has therefore created a new program named "ODiN" (short for Operating Disaggregated Networks) which reflects exactly on this paradigm shift, and plans to provide a solid and meaningful guide to operators, industry partners and telecommunication ecosystem players in general on how to execute this journey successfully.

2 EXPECTED BENEFITS OF NETWORK DISAGGREGATION

The agility and flexibility of disaggregated networks has the potential to provide many benefits, as identified below, to be further explored and possibly modelled. It is also expected that a parallel and equal improvement in how operators can operate those networks leverage on the native tools and best practices that come within a disaggregated and cloudified ecosystem. Many of these aspects have an impact on the operating model in terms of for example new technologies to master or new processes to set up to take full advantage of the provided benefits.

2.1 Adoption Flexibility

2.1.1 More Solution Choices and Flexibility

Disaggregation enables a multi-vendor environment. Vendors can focus on a subset of the whole pack of solutions which once was expected to be provided by a single vendor. This in turn will allow the vendor to specialize on specific products and allocate its resources on those. It is expected this will provide more focus and more competitive products for the same functionality. When this is replicated by more companies, there will be more competing brands and products in the telecommunication market. This has not happened in the past to such extend.

Now, with lowered entrance barrier and more suppliers in the market, we expect there will be more choices for the operators to select from. This will also enable them to mix and match based on their needs (best of breed approach). Operators for example can now source a Radio Unit (RU) from a different vendor than those of a Distributed Unit (DU) and Centralized Unit (CU). They could choose the best RU, DU or CU and they could do more combinations for each area or cluster type. Some operators who have internal Research and Development Teams and are engaged in industry testing and development initiatives may be able to develop solutions faster and customize solutions based on their needs. Bottom line is, it is expected that users get more value for their subscription as disaggregation allows more opportunities to make operator networks more efficient with improved performance.

One of the many advantages of disaggregation is the separation of software from hardware. This is actually the key factor that allows more flexibility because hardware and software are now developed separately. This allows more innovations on both.
Aside from allowing more developments in software, operators will also have more choices or options in terms of hardware. Since COTS (Commercial Off-The-Shelf) can now be used, IT branded hardware could also be used for telecommunication applications. This should enable operators to acquire the best and latest hardware. Latest technologies and functionalities then could easily be deployed using software upgrades. It is expected this will also allow a faster time to market.

2.1.2 Supply Chain Benefits

On one hand, disaggregation adds the possibility and capacity to ensure a more diverse supply chain, sourcing components from vendors of multiple geographies and therefore allowing for more resilient networks and processes.

On the other hand, global operators could have more opportunities to localize the supply, giving opportunities to competent local companies. This may encourage more local suppliers to develop solutions and join the telecommunication business. Hence, this should allow operator procurement to have more options in terms of capabilities and pricing, making the supply chain healthier.

2.2 Innovation Acceleration

2.2.1 Better Functionality, Features and Solutions

Disaggregating or breaking the network components into more parts and opening the interfaces will allow more companies, even the new and smaller ones, to develop solutions as well as hardware and software products. This will allow faster development of technology as more minds, teams and companies are working towards one goal – improving solutions, customer experience, making the network more efficient and lowering cost.

Disaggregation will also allow for more and better customization of products based on the specific needs of each operator. Operators are able to buy only the features and functionalities that they need. It is expected that this will translate to a more efficient solution.

2.2.2 Better Performance, Improved User Experience

Increased developments in each part of the network are expected to cause better KPIs and improve performance in mobile networks. These developments will allow each network component to contribute to a better performing system and will ultimately lead to better end-user experience and improved services. Better performance could also translate to a higher revenue.

2.2.3 Speed of Change

Increased competition due to lowered barriers to enter will also provide incentives to vendors who will develop better and more efficient products that in effect develops the market as a whole. This will benefit the operators even more as it is expected that technology will keep on getting better in a shorter span of time. The level of flexibility, which affects the speed of change, will be dependent upon the development of each vendor. It is assumed that some will be more flexible, and some will be less flexible. With this, some will be capable of being faster than others. At any rate, changes to the network will be faster compared to today. This will allow operators to scale their networks better based on their needs.

Due to more granularity and flexibility of solutions, operators will be able to do expansions, upgrades or any changes with less effort and faster. By disaggregating the network, operators can make up the network with each piece of network function that fulfils the network demand. Each network function acts as a component and provides a simple function for a complete network service. With the simplicity of each component, operators can upgrade each part singularly as opposed to upgrading the entire network. This greatly improves the life cycle of network services and time-to-market. This will let operators fit in the new era quickly and provide new network services.

2.3 Expenditure Reduction

2.3.1 Lower Cost Attributed to Improved Competition

One of the promises of disaggregation and open interfaces is lowering cost, with expectations for specific network domains such as RAN to reach 30% to 40% lower CAPEX and OPEX (source: https://opennetworking.org/news-and-events/blog/5g-transformation-with-open-source-

spotlight-wrap-up/). As networks continue to expand, develop and transform, operators need to invest significantly. Operators are trying to reduce TCO and spend of the network. Lower TCO could translate to lower service prices for subscribers or more benefits and features for the same cost.

2.3.2 Assumed cost gains attributed to improved Resource Efficiency

Disaggregation allows operators to centralize functions and control. This enables better efficiency by leveraging on pooling gains which could also translate to lower CAPEX and maintenance cost.

Since software and functionalities are disaggregated, they could be installed or housed on shared hardware. With this, operators could implement a common hardware or infrastructure from RAN, Edge to Core in order to simplify engineering, implementation and operations. It is assumed this leads to reduced costs by leveraging on economies of scale.

2.4 Openness for Further Innovation in Automation and AI Platform

By disaggregating the business capabilities and control capabilities in the network, common capabilities are achieved and provided in a "platform" way. A unified AI platform is built, where specific services could be called through network elements.

The unified AI platform can provide intelligent application R&D with infrastructure services including centralized computing power, algorithm frameworks and general AI capabilities, realizing one-stop management of network intelligent application R&D, operation and maintenance.

After disaggregation of the network's business capabilities and intelligent capabilities, independent R&D can be carried out based on the AI platform, promoting R&D efficiency improvement and cost reduction.

3 CONTEXT, CURRENT CHALLENGES AND NEEDS OBSERVED BY THE OPERATORS

Benefits outlined in the previous section will not be achieved unless the industry manages to overcome a number of challenges.

3.1 Impacts to the Network

3.1.1 Complexity

Making solutions more flexible and scalable has an inherent challenge which is complexity. As hardware and software are separated, as well as their individual development, the overall solution becomes more complex because there are more and more solutions available that need to be able to work together.

As each company developing different parts has different roadmaps, the complexity that it will bring will add to the challenge of compatibility and interoperability, which operators are currently experiencing, including with traditional partnership model vendors. Comparing to traditional situations, where one company or vendor is providing the entire solution, no matter how complex the solution is, they can ensure compatibility of all components so the whole system or the solution is working as one and as intended. This will not be the case with disaggregation. It is expected that there will be many potential misalignments between products from different vendors due to the separate and independent development, which causes more complexity to the whole system. This can be observed in the current situation with traditional partnership model vendors who have been developing solutions and following 3GPP standards for many years and yet are still facing complexities. More needs are expected when there are newcomers who will also aim to integrate.

3.1.2 Interoperability and compatibility

The move to a disaggregated network solution needs to go hand in hand with the assurance of interoperability and compatibility. Operators must not find themselves in a situation where vendors are pointing at each other on how to integrate or problem solve when the customer experience and brand value is on the line. This is the part where operators need to be assured as this will impact network quality, customer experience, time to implement, optimization and

maintenance. In having multiple and many suppliers, one of the major concerns is interoperability.

Interoperability issues can only increase in the near term with the longer term aim to reduce these issues.

Currently, most if not all, traditional partnership model vendors who are complying to 3GPP and other telecommunication standards are also performing interoperability tests with each other. Yet, operators are still encountering interoperability issues especially on inter domain connections or interfaces. This is for instance caused by each vendor applying their own interpretation of the standards. It is anticipated that this will escalate further, rather than improve, when disaggregation is introduced into the networks since there will be more types of solutions and vendors to connect. Each of these solutions may have different and independent developers, roadmaps and interpretations of the standards leading to different implementations. They also have different timelines in terms of development, e.g., typically software has a faster development cycle than hardware. Therefore, it has to be expected that compatibility and interoperability will be a huge challenge.

3.1.3 Security Risks

The emergence of new and multiple vendors demands security assurance. Traditional partnership model vendors have seen many potential problems borne out of their long and vast experience of providing network solutions. Over many years, they have made efforts to harden and improve the security of their solutions, components, software, hardware and even their functions. Security development has been part of their DNA because they themselves have experienced solving problems that resulted from vulnerabilities. Now the question is, are the new vendors able to cope up and able to ensure keeping the networks safe from those vulnerabilities and security threats the same way the traditional partnership model vendors did? Or maybe even better?

Furthermore, as more components and functionalities are introduced caused by disaggregation, the network potentially becomes vulnerable as there are more integration points. This could arise in the open interfaces, open-source software and off the shelf solutions. Functional splits and Edge computing could also contribute to wider physical attacks.

Disaggregation, if hosting software to the public cloud, could also introduce more vulnerabilities and attacks as the network tends to be more exposed to the public domain.

More components and splits also mean more challenges, which in turn could introduce yet another potential threat. Traditionally, only backhaul was considered as transport; there are now front haul, mid haul and back haul. This again introduces more possibilities for attacks.

In addition, having multiple vendors could furthermore introduce another type of security concern. Different software and different hardware might cause new vulnerabilities as they are developed separately. Each of these vendors or companies have different experiences towards attacks. This is where consolidated monitoring becomes essential. Each of the software and hardware needs to be fully monitored to detect any possible intrusion.

Multiple patches and updates could also introduce incompatibility and security risks across different versions. The need to maintain backwards compatibility and have a strict regression testing regime will be key to maintain security.

3.2 Impacts to the Organization and Processes

3.2.1 Impact to Procurement Processes

Disaggregation will have a huge impact in the supply chain and procurement strategies and processes. The number of suppliers will increase and this may mean that the procurement team needs to expand to be able to handle more suppliers.

Though disaggregation brings a huge benefit by expanding the telecommunication ecosystem, it will also cause complexity to the system and processes, as more vendors would need to be managed. Different vendors/suppliers have different SLA's, hence the variables in purchase and delivery will tend to broaden. More bricks lead to bigger challenges - both technical and legal/contractual.

Responsibility delineation is also expected to be a huge challenge to the supply chain. Procurement teams may encounter difficulties in identifying who should be responsible for a specific purchase, warranty, operations, etc.

More and smaller components mean more parties (either new players, or existing players that were masked by integrators/vendors in the past) to deal with. There will be new software components which again means more parties to cooperate with. New players (including possibly start-ups) will impact our current processes/habits to interact with the industry players.

3.2.2 Newly Added System Integration Processes

3.2.2.1 Changes in the Organization and Processes

The huge impact and changes brought about by disaggregation will cause an impact to the organization of each of the operators.

System integration is one of the biggest challenges in adopting disaggregation, since this was not typically part of the organization during the traditional or legacy days. So, the operators would need to either build their own team of system integrators or tap an external entity or company that will do system integration for them. Both options will entail huge effort, adjustments, changes in the organization, and potentially also additional cost.

Now, almost all the system integration work is being done by the vendors of the respective equipment. Typically, operators' biggest responsibility is interfacing and understanding the needs of the business, translating them to technical solutions, planning the implementation, decision making and governance. The rest is mostly passed on to the vendor for execution – from detailed design, to implementation, optimization, and maintenance.

Now that with disaggregation networks are broken into smaller parts, the responsibility of bringing everything together cannot be passed on anymore to a single vendor because of this new multi-vendor environment. There will no longer be a single vendor taking care of the overall solution and its management. The responsibility of successful integration will now be on the shoulders of the operator.

If the operator decides to build its internal system integration team, it will have to make either major rearrangements to re-purpose manpower or hire significant resources to fill the gaps. There will also be a massive change and adjustments in the processes of the organization. Coming from a set-up where much is done by the vendor, to the operator playing a bigger role in terms of putting everything together, from design to operations and management, will entail change at all organisational levels of the operator.

Integration is said to be a huge challenge for the operators. On the other hand, it will also be challenging to the vendors. They would need to be more conscious of what the other vendors are doing and developing as they need to interoperate. This fact would need to be considered also by procurement to ensure nothing is missed in the process or purchase.

3.2.2.2 Many Components and Companies to Deal With

At the moment, operators are talking to at least two to four vendors at most per domain. With disaggregation, operators could be talking to more than five for RAN alone. That could even go higher if they choose to be more flexible and choose more vendors. That will add to the complexity, not only to the solution, but also to the organization and processes of the company. Firstly, it is assumed that operators need to add more manpower to handle such vast number of vendors. Secondly, operators need to adjust their procurement processes and strategies to adopt to more vendors supplying the requirements. The separation of software and hardware alone will instantly add to the complexity as operators are historically used to buying both software and hardware from the same vendor. Having them separate would mean there will be separate services for each. This may not only add to the cost but make things more difficult as operators will talk to more people and have more interfaces.
The challenge will truly come during implementation, troubleshooting and problem resolution. Operators would need to talk to at least two entities for a single node.

3.2.3 Assumed Cost Implications

3.2.3.1 Additional Efforts – Integration, Training, etc.

System integration is normally not part of what operators spend on at the moment, as the same vendor is supplying both the hardware and the software. There is no integration needed because software is already integrated in the hardware. The beauty of the current set-up is its simplicity.
With disaggregation, since software is separated from hardware, operators would need to have an integration team that will combine or install the software to the hardware making sure of its compatibility, to facilitate proper operation of the equipment or the network function. This will either need a separate vendor or a formation of a new team within the company. This will definitely translate to another additional effort and potentially cost.

Now the question is "will it really be worth it?". Will the expected decrease in cost and the new business possibilities enabled by the new ecosystem, attributed to the separation of hardware and software, offset the operational changes that need to be made? Will the cost reduction cover for the needed offset and still maintain a worthwhile net decrease in TCO? Will all the efforts be compensated in the long term? Those questions need to be answered. Otherwise, the decision making will be very hard as everything needs to be justified given that the current set-up and system is working well. There is a saying that goes "Do not fix something that is not broken". The current system and solutions are not broken, but are they flexible enough to sustain the new possibilities and services of the upcoming years? Disaggregation is there because of the industry's desire to make things better and more efficient. It better be worth it.

Training and competency are another effort in doing so. If operators decide to build a new Integration team within their company, operators would need to spend time and budget to build the competency and expertise of that team. On the other hand, if operators decide to outsource system integration, they would still need to develop the competency of manpower who will govern external SI.

Layers added to RAN could also introduce cost to both CAPEX and OPEX , as more components are needed.

3.2.4 Shift of Scope and Responsibilities

3.2.4.1 Who is Responsible

The breaking of a whole system into parts raises the question "Who is responsible?". This will be highlighted especially when there are network issues or collective customer complaints where there is a problem in the network that hasn't been identified yet.
In the traditional process, a single vendor would conduct tracing of the whole network and identification of problem and isolation is anticipated easier because that vendor has all the counters and measurements for each part of the network, therefore it is easier to identify which part of the network is causing problems. Since that vendor is providing all the parts and solutions to the whole system, only one entity or company is responsible. Therefore, escalation and troubleshooting should be simpler.
With disaggregation, even in one node, several vendors might be involved. Say in a gNode B, one vendor might be supplying hardware for CU, another for DU and another for the software

of both or one of these functions. Then another vendor is supplying RU and another for antenna. If say that gNode B or site is having performance issues, it is not straight forward to tell which component is problematic. Is it hardware or is it software? Or is it the combination of the two that causes the trouble? Even when the problem is identified, the escalation and troubleshooting won't be as easy as several teams from different parties may need to cooperate to solve the issue.

Let's take for example an extreme case in traditional solution having only one vendor for all the RAN components in the network. Since that single vendor handles and is responsible for the RAN of the whole network, it will have a large support system in terms of resources, tools, manpower, technical support, ticketing system that escalates all the way to R&D and main office. In that case, any issue in the network will be identified, troubleshooted and resolved by that single vendor who might have significant resources that could respond to an issue anywhere in the network, quickly. On the other hand, when network is disaggregated and the components of the network are handled by different vendors, each of those vendors would most likely have less or fewer resource supporting the networks. This might cause them to respond slower. This goes back to the bottom line and question again of "Who is responsible?".

To resolve this, there should be a central team that oversees and monitors all components. Then again, building and equipping this team won't be as easy as there are many different components in the network with different brands. That would mean additional effort as the team should be capable of monitoring and understanding all the components in the network. This again would imply effort on training and competency development and translate to OPEX.

One of the common questions is when there are major issues in the RAN network, who would identify if the issue is caused by the software or the hardware? There should be a way or a tool that could easily pinpoint that. Now the question arise on who will develop that tool and if that tool supports any software or hardware vendor, given the vastness of the ecosystem that is continuously growing until now?

Troubleshooting will eventually be more complex when networks get disaggregated. With that, it can be expected that vendors can differentiate themselves through support offerings.

3.2.4.2 Software Asset Management (SAM)

Dealing with software components will require proper licensing and asset management: The choice of licensing model should be adjusted to the use cases. Concerning the duration of the rights of use, the "rental" model (i.e., subscription) could be considered with caution to avoid explosion of OPEX and perpetual rights should be preferred to optimize investments. On the other hand, as cloud services are generally monetized based on their usage, it is logical to reflect this model on the licenses of network functions, which will have to be based on "Pay-as-you-Use" models. This means that usage rights must be quantified based on usage metrics related to the value generated by the network function.

- The potential impact of a significant increase in operational costs related to the SAM process throughout the life cycle of VNF/CNF, from procurement to decommissioning, could be mitigated by an adapted tooling approach, to guarantee usage compliance while controlling operational costs. Automation of SAM processes is therefore essential, just like other business processes of the operator. This automation is only economically feasible if this process can be applied in a unified manner to all network software and regardless of the suppliers. This is best possible if this is based on standards.
- The purchase of licenses adapted to the usage implies being able to estimate this usage at a certain time in the future. This can be done by observing the evolution of current usage, but this is not sufficient. Network functions can be viewed as being “organized/deployed” as “stacks” (in a “client/server” or “vertical” type of association) and “service chains” (i.e., in a “horizontal” type of association). To simplify, it can be said that it is useless to buy usage rights for a function if the usage rights of the one(s) on which that function relies would not allow to exploit them. On the other hand, it is useless to buy usage rights for a function that is part of a chain of functions (Network Service), if the usage rights of one of the functions in the chain would not allow to exploit them. It is therefore considered necessary to be able to consider the management of usage rights for network functions in a comprehensive way.

It is therefore evident that the mobile network operators along with their partners are facing a major paradigm shift with network disaggregation. This is both a result of digital transformation and its enabler and accelerator. It promises a great deal of prospects, not the least of which is the mere ability to respond to demands of socio-economic transformation, increasingly mobile, connected and smart societies, and automated industries. This paradigm shift, however, comes with a wide range of challenges, as highlighted.

Supported by a strategic pillar and mission of NGMN for 2021 and beyond, there is obviously a collective need to proactively master the route to and through network disaggregation. This is the first publication of NGMN's Operating Disaggregated Networks (ODiN) project, representing operators' view on the opportunities and challenges. It will be complemented by the next step in this journey, which involves joint work with the entire NGMN Partnership, including vendors, system integrators, and other interested parties, to address these challenges, work with relevant organizations, identify gaps and requirements, guide the ecosystem and develop operational models.

LIST OF ABBREVIATIONS

ASIC	Application-Specific Integrated Circuit
COTS	Commercial Off-The-Shelf
CU	Central Unit
DU	Distributed Unit
FPGA	Field Programmable Gate Array
GPU	Graphics Processing Unit
MNO	Mobile Network Operator used here to represent a provider of connectivity and services
RU	Radio Unit

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