

Laorrojwong, Benyathip; Makarathat, Natchaya

Conference Paper

Open-RAN: Changing Landscape of Competition under Bi-polarization of Telecommunications Policy?

24th Biennial Conference of the International Telecommunications Society (ITS): "New bottles for new wine: digital transformation demands new policies and strategies", Seoul, Korea, 23-26 June, 2024

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Laorrojwong, Benyathip; Makarathat, Natchaya (2024) : Open-RAN: Changing Landscape of Competition under Bi-polarization of Telecommunications Policy?, 24th Biennial Conference of the International Telecommunications Society (ITS): "New bottles for new wine: digital transformation demands new policies and strategies", Seoul, Korea, 23-26 June, 2024, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/302455>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Open-RAN: Changing Landscape of Competition under Bi-polarization of Telecommunications Policy?

Natchaya Makarathat and Benyathip Laorrojwong

Keywords: Open-RAN, Economics, Competition, Geopolitics, Bi-polarization, Conflicts, Technology policy.

Abstract

The Open-RAN model has recently been put to the forefront of debate on how the open networking technologies would benefit the telecom operator, vendors and tech sectors in terms of competition, freedom, and openness. The Open-RAN has introduced an open interface which allows telecom operators to choose their own combinations of hardware and software. In other words, Open-RAN might be replacing the traditional/old model, which offers bundle hardware and software, already integrated, in a monolithic architecture.

The traditional 5G tech architect uses proprietary equipment to connect devices to the network. This means all parts (hardware and software) of 5G network are manufactured by the same company. While this architecture guarantees compatibility and operability of the network, it also leads to the conduct of monopolies in the market as well as technology dependency. The new invention of Open-RAN model, in contrast, supports the disaggregation of hardware and software. In the simple terms, the operating system will come from Company A, antennas and cells will come from Company B, and a microchip will be used from Company C. This type of network architecture is designed to reduce the risk of dependencies and disrupt the nature of 5G monopolistic market.

The initial purpose of the Open-RAN, in this sense, is aimed at developing 5G network technology by using open interfaces, allowing operators to be able to use equipment from different manufacture. From the economics perspective, Open-RAN model promotes competition and innovations, avoids the formation of tech oligopolies, diversifies suppliers and mitigates risks, and importantly leads to a decoupling of bi-polarization of the U.S. and Chinese technology.

However, from the geopolitics dimension, the Open-RAN could be a testament of how American and European superpower ban Chinese (Huawei) gears and equipment from 5G network by creating a symbolic of technology that stands the value of freedom, openness, trustworthy and democracy. Washington tech policy under President Donald Trump has been made based on a concern over the dangers of installing networks from equipment that can be manipulated, disrupted, or even controlled by the Chinese government. In 2019, Trump's administration launched the "executive order" to ban the use of telecom equipment from foreign firms and companies, suspected to national security. The obligation to replace Chinese components from 5G networks has led to the initiative of alternative network equipment suppliers. Open solutions by the Open-RAN model, in this sense, will be a possible approach to replace a closed/old architecture. In 2020, Washington endorsed the Open-RAN technology and put it in the central strategy to contain China and exclude Huawei from 5G network.

Instead of mainly focusing on the technical concept of Open-RAN technology, this paper will look at the economics benefit of Open-RAN and examine the reaction of related stakeholders from geopolitics dimension regarding the decision on adoption of Open-RAN network. The research question will be centered at "Will the Open-RAN and its open standard increase the competition in telecom market under the tech rivalry of the Chinese and the American?"

The methodology of the paper is based on documentary analysis as well as gathering in-depth information from sector's stakeholders such as global tech vendors, local telecom operators, telecom regulators and tech academia. The analyzing concept will be framed by the context of economics in terms of costs, number of players, and

market entry as well as the context of geopolitics through the lens of tech diplomacy of the American superpowers and allies based on the ground of the Sino-American tech rivalry. For the clearer picture, tech policy and political lobbying for adopting open-RAN will be analyzed through the reaction of international actors such as countries in Europe and in Asia-Pacific.

After the examination, this paper finds that Open-RAN architectures, at the first look, opens up vendors market as well as create a competitive entry with its open interface solution. It also unlocks the propriety technologies by allowing operators to mix and match the hardware and software from different sources and vendors. However, a closer look, from economic and geopolitics aspect, suspects the benefit of the Open-RAN.

From economic context, it is true that Open-RAN brings about the competitive entry of the telecom's equipment market that flavor a multi-vendor environment. However, the questions have been raised regarding that the leading manufactures for Open-RAN such as Nokia, Ericsson and Huawei are already dominant in the market, combining revenue share of nearly 80%. The tendency of oligopoly in the Open-RAN equipment market is criticized for keeping the price high and slowing down the innovation. It is estimated that Open-RAN can cost roughly 70% of operator's expenditure, causing hesitation for mobile telecom operators to invest and switchover.

From geopolitics context, Open-RAN can be considered as an escape of the American superpower and its allies who want to avoid proprietary equipment and reduce national dependence on Chinese equipment with the reason of national security. In fact, Open-RAN is a mechanism in which Washington promotes to reduce the role of Huawei and Chinese manufacture in the establishment of 5G infrastructure. The U.S. government has strongly involved in tech policy lobbying for the expansion of the Open-RAN model to the allied countries, especially in Europe and Asia-Pacific, by forming "Open RAN Policy Coalition".

Open-RAN, in the end, can only be a prism of U.S. - China tech rivalry. The governments and regulators who are at the forefront of making tech decision have to weigh between geo-politics and

geo-economics. Factors such as economic opportunities, diplomatic relationship, security concerns, and tech dependencies could not be underestimated as mobile networks become the critical infrastructure, serving as the backbone of economy and society.

1. Introduction: From 5G Tech Battle to the Open-RAN

The relationship between technology and geopolitics has been closely connected. The picture has become clearer when Chinese technology has developed in a rapid pace and has started challenging the Great Power of the United States in tech-policy oriented, especially in the context of 5G networks. The Washington's reaction has been both defensive and offensive, especially on crucial high technology like chips and semiconductors. However, in the landscape of new technology, the key technology race has expanded far more than "hardware". "5G infrastructure and software", in this sense, has been increasingly critical in technology battle and geopolitics backdrop. In recent years, the tension has been escalated since Beijing has set its goal to compete with the U.S. in order to become a global leader in 5G infrastructure provider, causing what we have called Sino-American bipolarization.

The concern about the danger of installing 5G networks from equipment that can be manipulated, disrupted or even controlled by the Chinese government has led the U.S. and its allies to make decision to ban Chinese/Huawei Technology. The confrontation of the two rivals and their allies has a consequence in international politics. The situation, in this sense, has limited international actors and countries towards their scopes of actions in technology policy, security choices and levels of investments.

In response to a heated technology race, some part of 5G industry has been calling for an alternative and opened technology. The Open-RAN model has therefore been introduced. The new Open-RAN is an open and interoperable 5G architect that does not need to rely on proprietary equipment. The benefit of using open interfaces, allowing operators to be able to use equipment from different manufactures, is considered as a promise to ensure security, mitigate risk, and avoid national dependence on foreign equipment

manufacturers, while promoting competition and innovations by diversifying supplier and reducing the tendency of tech oligopolies.

2. Open-RAN: Definition, How it works, the Pros and Cons, and Current status

2.1 What is it and how it works

A mobile network comprises of two domains: the Core Network and the Radio Access Network (RAN). The RAN connects the users to the core network by sending and receiving radio signals from the users' devices through antennas on the towers and converting them into digital signals at the base stations. (Nokia Communication, n.d.)

In order to comprehend the true nature of Open-RAN, the evolution of RAN is necessary to mention. (Faisal, 2021, and Wypiór et al., 2022). Originally, the baseband unit (BBU) and remote radio unit (RRU) at the cell site are co-located in the core network, and this is where the traditional RAN connects to its users. The backhaul, in this architect, connects each cell site to the main network.

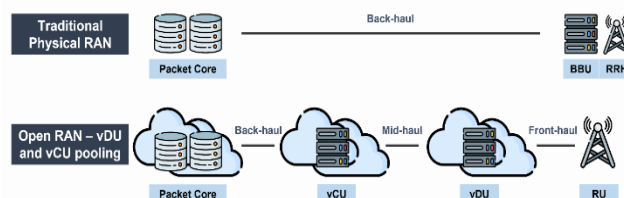
The evolution of Radio Access Networks (RANs) has been marked by a continuous drive towards separation of functional units within the base station. This trend, as documented by Wypiór et al (2022), stems from the desire to enable "one-to-many connections" between individual nodes, thereby paving the way for a multi-vendor approach within the RAN architecture. Despite this advancement, the interfaces connecting these nodes often remain proprietary. Consequently, mobile operators are left with limited options, often resorting to mature solutions from single vendors for ease of integration, optimization, and maintenance (de Geest et al, 2023).

The reliance on single vendor, even amidst the growing complexity and innovation in RANs, ultimately leads to vendor lock-in and its associated limitations, such as the lack of motivation to provide innovation or better prices from the vendors, causing the slower tech development and higher costs. (Nokia Communication, n.d.)

In the light of such limitations, Open-RAN was founded to enable the multi-vendor environment of RAN by disaggregating the network architecture into three main building

blocks, which are the Radio Unit (RU), Distributed Unit (DU), and Centralized Unit (CU), as well as ensuring their interoperability and flexibility through open protocols and interface using open standard. (Claydon, 2021) Open-RAN, in this regards, is not only physically disaggregated functional unit but also allows different vendors equipment to interoperate within the same network.

Figure 1: Overview of the traditional and open-RAN architect



Source: Analysys Mason (2022)

Not only the hardware and maintenance aspects that are the concern in Open-RAN development, but also the software that would be operated on top of the network. Open-RAN usually comes with RAN Intelligence Controller or RIC as a part of Open-RAN architecture. RIC is in charge of controlling and optimizing RAN function. (Juniper Network, n.d.) It makes controlling RAN elements and their resources in one second possible by delivering AI-based recommendations for network optimization. It also makes use of external enrichment data, including subscriber data, network data, and performance indicators in its analytics process.

It is reasonable to conclude that the emergence of Open-RAN has increased efficiency and has opened up a wide range of new opportunities while simultaneously decreasing vendor dependence and monopolization in the building network. With the emerging of Open-RAN, some vendors aim to provide both hardware and software that will be compatible with such open and disaggregated network architecture. However, Open-RAN cannot work unless all the hardware and software from different vendors are able to interoperate. Therefore, in this very early stage, the test of interoperability of the equipment and interface must be arranged in order to make the list of equipment and its vendor that fits to O-RAN's open standard.

2.2 The Pros and Cons: Technical and Economic Insights of Open-RAN

The Open-RAN model disaggregates the different parts of radio access network and gets connected through open interfaces. (Plantin, 2021) The new architect of Open-RAN could be replacing the traditional/old model, which offers bundle hardware and software, already integrated, in a monolithic architecture. From the tech industry, the open interface and modular architecture could be a promise to promote competition and innovation. However, some have suspected the benefit of the Open-RAN and has been questioning the possibility of tech adoption, fragmentation of tech standards, as well as the vulnerabilities of threat from multi-vendor's equipment. In this section, the paper will therefore discuss the debate of the Open-RAN model from the pro and cons sides through technical and economic perspectives.

2.2.1 The Pros

According to the Open RAN Policy Coalition¹, they believe that by “standardizing” or “opening” the protocols and interfaces between the various sub-components, such as radios, hardware and software, in the RAN, will establish an environment where networks can be deployed with a more modular design without being dependent upon a single vendor. Standardizing and developing open interfaces will also ensure interoperability across different players and potentially lower the barrier to entry for new innovators. (Openranpolicy, n.d.)

Open-RAN design, deployment, and operation are based on disaggregated, virtualized and software based components. It gets connected through open and standardized interfaces and is interoperable across different vendors. (Polese, Bonati, D'Oro, Basagni, & Melodia, 2022)

From technical point of views, the benefit of the Open-RAN is centered at two main elements:

- (1) *The disaggregation and virtualization* enables flexible deployments, which

increase the resiliency and the ability for configurability of the RAN.

- (2) *The open interface* allows operators to use different equipment from different vendors.

The Open-RAN architect, in this sense, unlocks the propriety technologies by allowing operators to mix and match the hardware and software from different sources and vendors. In the simple terms, the operating system can come from Company 1, antennas and cells can come from Company 2, and a microchip can be used from Company 3.

From economic point of views, the Open-RAN architect will open the ecosystem to the competition, allowing new players to offers services, creates more choices, as well as reduces costs. The detail is discussed as follows:

(1) Market and Players:

In the past, the RAN market is dominated by limited organizations that do not design their infrastructures to be interoperable. This architect therefore limits choices and options where network operators must depend on equipment from exclusively one vendor, creating a “vendor lock-in” situation. Without open interoperability standards, there is little space for new vendors at any level of the RAN market to get started.

When Open-RAN standards are widely adopted, network operators will have the options to select the equipment and software with features that best fit their needs. In this sense, the limitation arising from “vendor lock-in” will somehow disappear and will create a market entry for new equipment vendors to access to the market.

The landscape of multi-vendor, introduced by the Open-RAN architect led to a more competitive market, driving the market growth. According to data from Grand View Report (2023), global Open-RAN market size was estimated at USD 2,771.2 million in 2023 and is expected to grow at a compound annual growth rate

¹ **Open RAN Policy Coalition** represents a group of companies formed to promote policies that will advance the adoption of open and interoperable solutions in the Radio Access Network (RAN). Its membership consists of global technology companies, including: Airspan, Amdocs, AMD, American Tower, Analog Devices, AT&T, AWS, Bharti Airtel, Broadcom, Ciena, Cisco, Cohere Technologies, DeepSig, Dell Technologies, Deutsche Telekom, DISH Network, Fujitsu, Google, Hewlett Packard Enterprise, IBM,

Inseego, Intel, JMA Wireless, Juniper Networks, Kyrio, Ligado Networks, Marvell, Mavenir, Meta, Microsoft, NEC Corporation, Nokia, NTT, Nvidia, Oracle, Pivotal Commware, Qualcomm, Quanta Cloud Technology, Radisys, Rakuten Symphony, Red Hat, Reliance Jio, Samsung Electronics America, STL Tech, Texas Instruments, U.S. Cellular, US Ignite, Verizon, VMware, Vodafone, Wind River, and XCOM-Labs.

(CAGR) of 33% from 2023 to 2030. North America, comprising of developed countries such as the U.S. and Canada, is expected to hold the largest global Open-RAN market share, accounting for a share of more than 44% of the overall revenue in 2022. The growth are possibly caused by several factors, including the presence of prominent key players, such as AT&T, Inc., and the region's technological inclination towards early adoption of advanced solutions.

Asia Pacific is also potentially contributed to a significant growth of the Open-RAN. The region's growth is catalyzed from several factors, such as the increasing demand for advanced telecommunications infrastructure, a growing number of mobile subscribers, and government regulations. (Grand View Report, 2023) Countries, such as Japan, South Korea, and India, are at the forefront of regional growth due to their technological advancement and the rising emphasis on fostering a healthy and secured digital ecosystem.

The Open-RAN market is still in an early stage since technology is fairly new and the deployment of Open-RAN has been recently commercialized. However, the growing demand for flexibility and cost-efficiency offered by Open-RAN is contributing to the market's growth. Apart from vendors from China, the U.S., and Europe, there are also new market entrants from South Korea (Samsung), Japan (NEC, Fujitsu, Rakuten, KDDI) and Middle-east entering into the RAN market. Some of the prominent players in the global Open-RAN market are vendors from across regions. (Reports Publisher, 2023) The sample are as follows:

America: AT&T (U.S.), IBM (U.S.), Hewlett Packard Enterprise (U.S.), VMware (U.S.), Airspan Networks (U.S.), Mavenir (U.S.), CommScope (U.S.), VIAVI Solutions (U.S.), Amdocs (U.S.), XComunicação Labs (U.S.), DeepSig Inc. (U.S.), Celona (U.S.), Verana Networks (U.S.), Entel (Chile)

Europe: Ericsson (Sweden) , Nokia (Finland), Orange (France), TIM (Italy), Telefónica (Spain), Sivers Semiconductors AB (Sweden), NXP Semiconductors (Netherlands), Picocom (UK), Lime Microsystems (UK), Microamp Solutions (Poland)

Asia: Huawei (China), ZTE Corporation (China), Comba Telecom (China),

Samsung Electronics (South Korea), NEC Corporation (Japan), Fujitsu (Japan), Rakuten (Japan), Renesas Electronics (Japan), KDDI Corporation (Japan), Singtel (Singapore)

Africa and Middle East: MTN Group (South Africa), Etisalat UAE (UAE), Mobily (Saudi Arabia)

(2) Cost:

Proprietary products are typically more expensive than generic counterparts. Since there are not third-party RAN elements that can integrate into a RAN vendors' infrastructure, a network operator is trapped with one RAN vendor's products.

The benefit of the open interface standards is that third-party products can communicate with the main RAN vendor's infrastructure. Network operators, in this regards, can select or choose the less-expensive third-party product that runs on generic hardware. The fact that operators can deploy networks elements and equipment from a range of suppliers will establish an open ecosystem, lower barriers to entry as well as allow new players to offers products and services, leading to the competition in pricing.

In this sense, Open-RAN interface is assumed to reduce the cost of deploying the new 5G technology. According to Analysys Mason report 2022, Open-RAN has a potential reduce deployment cost by up to 30%. The Total Cost of Ownership (TCO) will be lower based on the following concept:

- **Capex** (capital expenditure):

The Open-RAN hardware and software components will reduce capex, compare to traditional physical components, which are costly and only available from a small number of vendors.

- **Opex** (operational expenditure):

By adopting the cloud native infrastructure of RAN technology, operator will not face with the 5G challenges in terms of densifying their networks by adding more sites. Also, the lower cost of Open-RAN hardware and software will result in the reduced vendor support and maintenance expenses, compared to the tradition RAN architect.

Analysys Mason has developed a Total Cost of Ownership (TCO) of disaggregate

and Open-RAN model, compared to the traditional physical RAN for 5G, with the collaboration with Wind River². Analysys Mason has also identified 3 different types of operator profiles based on architect assumption and scenario assumptions as follows:

- **Operator profiles**

- (1) A large size operators in Western Europe
- (2) A medium sized incumbent operators in a developed market
- (3) A large size operators in developing market

Detail	(1) A large size operators in Western Europe	(2) A medium sized incumbent operators in a developed market	(3) A large size operators in developing market
Country population	60,000,000	40,000,000	60,000,000
Market share of subscribers	33%	33%	33%
5G coverage (within 3 years)	35%	35%	35%
Total number of RAN sites (within 3 years)	2,000	1,700	900

- **Architect assumptions**

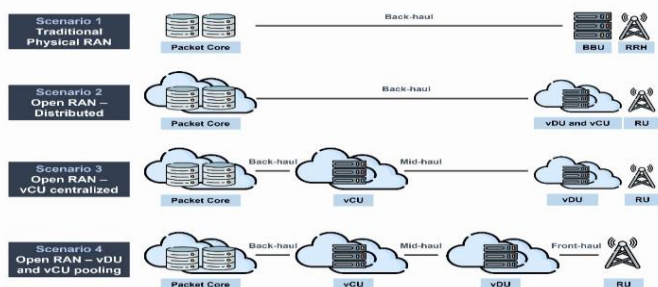
Architect	Assumption
Radio spectrum	Mid-band 5G: 3.5 GHz (100MHz) and 700MHz
Geography	5 geo-types based: dense urban, urban, suburban, rural, very rural
Capex parameters	Hardware (Physical RAN) , software (Open-RAN) Cell site passive infrastructure (towers, poles) is excluded
Opex parameters	Headcount, power, support and maintenance
Length of analysis	3 years

Source: Analysys Mason (2022)

- **Scenario assumptions**

- (1) Traditional physical RAN (**scenario 1**)
- (2) Open-RAN: distributed (**scenario 2**)
- (3) Open-RAN: Centralized (vCU)³ (**scenario 3**)
- (4) Open-RAN: Fully Centralized (scenario 4)

Figure 2: Architect of Model Scenario



Source: Analysys Mason (2022)

² Wind River is a distributed cloud company for vRAN and Open-RAN deployments.

³ This allows vCU pooling in a remoted data center, providing a better software Capex and Opex. However, it

- **Scenario cost outcome**

Compared to the traditional/old architect (scenario 1), the result of the model shows that if adopting the distributed Open-RAN (scenario 2), a large size operators in Western Europe can save up to 22% of cost saving, while a medium sized incumbent operators in a developed market and a large size operators in developing market will save up to 20% and 13% of cost saving accordingly.

Table 1: Total Cost of Ownership for a large size operators in Western Europe

Component	Scenario 1 Traditional physical RAN	Scenario 2 distributed Open-RAN	Scenario 2, compared to Scenario 1	Scenario 3 Centralized Open-RAN	Scenario 3, compared to Scenario 1
Total capex	USD 69,922,062	USD 53,553,923	-23%	USD 53,452,593	-24%
Total opex	USD 29,785,748	USD 24,700,764	-17%	USD 24,882,417	-16%
Total Cost of Ownership (3 Years)	USD 99,707,810	USD 78,254,687	-22%	USD 78,335,010	-21%

Table 2: Total Cost of Ownership for a medium sized incumbent operators in a developed market

Component	Scenario 1 Traditional physical RAN	Scenario 2 distributed Open-RAN	Scenario 2, compared to Scenario 1	Scenario 3 Centralized Open-RAN	Scenario 3, compared to Scenario 1
Total capex	USD 52,740,607	USD 41,051,510	-22%	USD 40,974,939	-22%
Total opex	USD 22,385,286	USD 19,131,690	-15%	USD 19,239,293	-14%
Total Cost of Ownership (3 Years)	USD 75,125,893	USD 60,183,200	-20%	USD 60,214,232	-20%

Table 3: Total Cost of Ownership for a large size operators in developing market

Component	Scenario 1 Traditional physical RAN	Scenario 2 distributed Open-RAN	Scenario 2, compared to Scenario 1	Scenario 3 Centralized Open-RAN	Scenario 3, compared to Scenario 1
Total capex	USD 23,654,267	USD 20,509,654	-13%	USD 20,439,834	-14%
Total opex	USD 7,362,267	USD 6,486,085	-12%	USD 6,142,670	-17%
Total Cost of Ownership (3 Years)	USD 31,016,534	USD 26,995,739	-13%	USD 26,582,504	-14%

Source: Analysys Mason (2022)

Interestingly, if adopting the centralized Open-RAN (scenario 3), in which the vCU is pooling in a remoted data center, will technically provide a better software Capex and Opex. However, it might lead to addition hardware server and power consumption cost in data center. This will be

might lead to addition hardware server and power consumption cost in data center.

possible to outweigh the gains from the reduction in software cost. However if operators are able to utilize spare data center capacity without incurring the additional data center costs, scenario 3 would yield the better TCO than scenario 2. For instance, a large size operators in developing market can reduce cost about 14% of cost saving from scenario 3.

Apart from 3 scenario assumption, Analysys Mason also went beyond by testing whether if adopting fully centralized Open-RAN (Scenario 4) would better the cost in capex and opex. The result shows that, in western market, the pooling of vDU/vCU away from the cell site in suitable network locations potentially offer the greater efficiency benefits over all the model scenarios. However, this scenario is not realistic and not practical for many operators since it requires a lot of investment and need available fiber in the fronthaul to meet the latency requirement as well as the availability of far edge data center.

Analysys Mason therefore presumed that a large size operators in Western Europe is only player that would fit scenario 4 model since they already have the fronthaul fiber infrastructure in place and have access to edge data center locations. The results shows that by pooling vDU/vCU, it can offer up to 30% of TCO saving over 3 years.

Table 4: Total Cost of Ownership for fully centralized Open-RAN (Scenario 4) for a large size operators in Western Europe

Component	Scenario 1 Traditional physical RAN	Scenario 4 fully centralized Open-RAN	Scenario 4, compared to Scenario 1
Total capex	USD 69,922,062	USD 46,716,161	-33%
Total opex	USD 29,785,748	USD 22,722,292	-23%
Total Cost of Ownership (3 Years)	USD 99,707,810	USD 69,438,453	-30%

Source: Analysys Mason (2022)

From the model's result, it shows that the Open-RAN will offer cost savings for operators if they decide to start adopting the Open-RAN with the right technology path and ecosystem. TCO reduction is one of a key reason for operators to move from the traditional RAN architect to the Open-RAN ecosystem. However some are not yet convinced since this Open-RAN technology is fairly new and is not widely adopted globally.

2.2.2 The Cons

Despite the benefit of Open-RAN for mobile network operators to be able use equipment from different manufactures, creating a flexible and competitive ecosystem, leading to lower total costs of ownership (TCO) and innovation in the telecommunications industry, some parts of the industry are not yet convinced and are raising concerns in the following aspects.

(1) Market concentration

It is true that Open-RAN brings about the competitive entry of the telecom's equipment market that flavor a multi-vendor environment. However, the questions have been raised regarding that the leading manufactures for Open-RAN, such as Nokia, Ericsson and Huawei, who are already dominant in the market, combining revenue share of nearly 80%. (Plantin, 2021) The current market concentration calls into question regarding the possibility and ability of new entrants in the market if the leading incumbent manufacturers have been already dominant in the market and have involved in the technology design.

The tendency of oligopoly in the Open-RAN equipment market, in this sense, is criticized for keeping the price high and slowing down the innovation. It is estimated that Open-RAN can cost roughly 70% of operator's expenditure, causing hesitation for mobile telecom operators to invest and switchover.

(2) Cost

Open-RAN is often promoted as a cost-effective solution since it is promising to reduce the cost of network operators both in opex (operational expenditure) and capex (capital expenditure). However, data from interviewed operators (Analysys Mason, 2022) shows that operators need to make a lucrative upfront investment, especially for skill acquisition. The skill set level is very crucial in order for operators to meet level of operational automation in the Open-RAN and could native infrastructure.

(3) Security and tech fragmentation

Open face, offered by the Open-RAN architecture, has raised security concern. The multiplication of open faces can expand the threat surface for possible cyber-attacks. (Plantin, 2021) The presence of the many Chinese players in the

O-RAN Alliance⁴ and the ability to access to the code and intellectual property can be perceived by the West as a potential risk. The risk can also be witnessed in a fragmentation of tech standards as well as a lack of common interfaces, which can hinder the interoperability.

2.3 Current Status: Worldwide embrace?

The benefit of the Open-RAN, based on an end-to-end, cloud-native, and open network, is not only challenging traditional methods and incumbent infrastructure vendors but also representing a reset for the 5G industry and a disruption that is currently dominated by incumbent technology. To push forwards the development and adoption of the Open-RAN, there are many organization involved. For example:

- In 2016, **Telecom Infra Project (TIP)** emerged as a collaborative platform for operators, vendors, and start-ups to drive innovation and cost reduction in the telecom equipment sector. TIP championed open source technologies and collaborative approaches, laying the groundwork for a more Open-RAN ecosystem.

- After in 2018, **O-RAN Alliance** was established as a global coalition consisting of both mobile operators and vendors dedicated to developing and implementing Open-RAN principles. This marked a significant step towards standardizing an open and intelligent RAN architecture. The initial whitepaper, "Towards an Open and Smart RAN," outlined the core vision and guiding principles for Open-RAN adoption.

- In 2020, **Open RAN Policy Coalition** was launched. It is a coalition formed by a group of companies consisting of the U.S. hardware and software providers both small and large companies, and technology companies both U.S. and non-U.S. companies.

- On the software development side, **O-RAN Software Community (OSC)** was formed as an open-source initiative to develop software components compliant with Open-RAN specifications. This has fostered a collaborative environment for building and sharing Open-RAN software, accelerating the eco-system's growth.

Due to the beginning phase of the technology, adoption and deployment of Open-RAN on 5G is still limited. Based on O-RAN map provided by the O-RAN Alliance, there are some recent developments of Open-RAN as follows (O-RAN Alliance, n.d.):

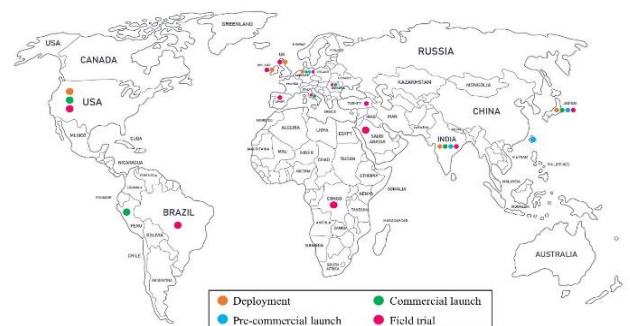
- **Deployment:** United States (AT&T), United Kingdom (Vodafone), Ireland (Vodafone), Germany (1und1, Deutsche Telekom), Japan (KDDI, NTT Docomo, SoftBank, Rakuten Mobile), and India (Airtel, Vodafone).

- **Commercial launch:** United States (DISH Wireless), Peru (IPT), Germany (1und1), Italy (TIM), Romania (Vodafone, Orange), India (Airtel), and Japan (KDDI, NTT Docomo, SoftBank, Rakuten Mobile)

- **Pre-commercial launch:** Germany (1und1), India (Airtel), Taiwan (Chunghwa Telecom), and Japan (KDDI, NTT Docomo, SoftBank, Rakuten Mobile)

- **Field trial:** United States (TELUS), Brazil (TIM), Ireland (Vodafone), United Kingdom (BT, Virgin Media/O2), Germany (Telefonica, Deutsche Telekom), Italy (Vodafone), Spain (Vodafone), Romania (Orange), Turkey (Vodafone), Democratic Republic of Congo (Vodafone), Saudi Arabia (stc), India (Airtel), and Japan (KDDI, NTT Docomo, SoftBank, Rakuten Mobile)

Figure 3: Open-RAN map



Source: O-RAN Alliance

⁴ **O-RAN Alliance** is a world-wide community of mobile operators, vendors, and research & academic institutions with the purpose to re-shape Radio Access Networks (RAN) to be more intelligent, open, virtualized and

fully interoperable. As of May 2023, nearly 330 carriers and vendors belong to the alliance, which has grown into a global and large industry association.

- **Testing:** United Kingdom (BT, Vodafone), France (Orange), Spain (Telefonica), Germany (Deutsche Telekom), South Africa (Vodafone), Mozambique (Vodafone), India (Airtel), Taiwan (Chunghwa Telecom), South Korea (SK Telecom), and Japan (KDDI, NTT Docomo, SoftBank, Rakuten Mobile)
- **MoU:** Brazil (Telefonica), United Kingdom (Vodafone, Deutsche Telekom, Orange, Telefonica, TIM, NTT Docomo), France (Orange), Germany (Deutsche Telekom, Orange, Telefonica, TIM, Vodafone), Spain (Deutsche Telekom, Orange, Telefonica, TIM, Vodafone), Italy (Deutsche Telekom, Orange, Telefonica, TIM, Vodafone), India (Airtel), South Korea (NTT Docomo), and Japan (Vodafone, KDDI, NTT Docomo, SoftBank, Rakuten Mobile)

3. Open-RAN: Tech Policy from Geopolitics Perspective

3.1 A New Battle of Tech policy?

With the rise of China in global technology sector, the U.S. strategic competition towards China will be based on the belief that China is America's primary threat (Bateman, 2022). In response to that, the American techno-nationalism has been prevailed in the Washington. The U.S. actions towards China have been heavily pushed to involve in restrictive measures with the ultimate purpose to contain Chinese technology threats.

This tech-nationalism policy first took place during former president Barack Obama's second term and was elevated and implemented under Donald Trump's administration. In May 2019, Trump banned Huawei from the U.S. 5G networks and announced sanctions that forced Huawei to overhaul the supply chain. (Nocetti,

2022) Later, an executive order was signed. The executive order gave the government's power to block the transfer of any technology relating to critical infrastructure, digital economy, and national security to China. (US Department of Commerce, 2019) In other words, the order has become a measure to control Chinese access to American market, key's technology and know-how.

In addition to ban Huawei from network and infrastructure, President Trump also bought Open-RAN to the center of tech strategy in order to secure network and infrastructure. While 5G industry originally invented the Open-RAN for the sake of competition and innovation through the open interface, Trump administration has used Open-RAN as a technology propaganda to create a trust and transparency ecosystem. Open-RAN, in this sense, has not been only an alternative 5G technology but also a mechanism to promote tech ideology to Washington's allied countries to block untrustworthy of Chinese gears and equipment.

The political interest of the U.S. government behind open-RAN was prominent through the following reactions:

- **In April 2020, Utilizing Strategic Allied Telecommunications Act or USA Telecommunications Act was passed.** This Act established a program through which the Department of Commerce will award grants to support the deployment and the use of Open-RAN 5G Networks throughout the United States. (Congress.gov, n.d)
- **"Open RAN Policy Coalition"** has been formed in 2020. The Open RAN Policy Coalition⁵ is a group of companies formed to promote policies to adopt the open and interoperable solutions in the Radio Access Network (RAN) as a means to create innovation, spur competition through multivendor approach, and

⁵ Membership consists of global technology companies, including Airspan, Amdocs, AMD, American Tower, Analog Devices, AT&T, AWS, Bharti Airtel, Broadcom, Ciena, Cisco, Cohere Technologies, DeepSig, Dell Technologies, Deutsche Telekom, DISH Network, Fujitsu, Google, Hewlett Packard Enterprise, IBM, Inseego, Intel, JMA Wireless, Juniper Networks, Kyrio, Ligado

Networks, Marvell, Mavenir, Meta, Microsoft, NEC Corporation, Nokia, NTT, Nvidia, Oracle, Pivotal Commware, Qualcomm, Quanta Cloud Technology, Radisys, Rakuten Symphony, Red Hat, Reliance Jio, Samsung Electronics America, STL Tech, Texas Instruments, U.S. Cellular, US Ignite, Verizon, VMware, Vodafone, Wind River, and XCOM-Labs.

expand the supply chain for advanced wireless technologies including 5G. (Open RAN Policy Coalition, 2024) However, when looking at the membership list of coalition, it is clearly seen that membership exclusively consists of companies from the U.S. allied countries, such as Germany, UK, Japan, South Korea, without the presence of Chinese telecom and manufacturers.

- In May 2020, following the request of the Department of State, the Center for Strategic and International Studies (CSIS) assembled a group of 25 experts from Asian, European, and U.S. companies and research centers to develop criteria to assess the trustworthiness of telecommunications equipment suppliers, known as **Network's Digital Trust Standard**.
- In August 5, 2020, "**Clean Network Program**" was launched. The objective of the program is to safeguard the nation's assets including citizens' privacy and companies' most sensitive information from aggressive intrusions by harmful actors, such as the Chinese Communist Party. The Clean Network Program is a creation of international acceptance on "Digital Trust Standards" (U.S. Department of State, n.d)

The Clean Network Program has produced a series of recommendations to determine trustworthiness and security networks such as a Criteria for Security and Trust in Telecommunications Networks and Services. The Criteria has complemented the work of the Prague Proposals⁶ and the European Union's 5G Toolbox⁷. These criteria rely primarily on publicly available

information to allow for an assessment of the trustworthiness and security of a potential supplier and to describe domestic policies and necessary actions to safeguard telecommunications networks.

Clean Network Program sets its part clearly not to use any transmission, control, computing, or storage equipment from untrusted IT vendors, such as Huawei and ZTE, which are required to comply with laws and directives of the Chinese Communist Party.

Regarding the Washington's interest behind the Open-RAN, it can be presumed that Open-Ran Technology is somehow a political discourse constructed by the U.S. government to ban Chinese technology. It also reflects the U.S.'s technological protectionism and the fear of losing its tech superiority to Beijing. From the geopolitics dimension, the Open-RAN is not a new battle of technology; however, it could be a testament of how American and European superpower ban Chinese (Huawei) gears and equipment from 5G network by creating a symbolic of technology that stands the value of freedom, openness, trustworthy and democracy.

3.2 Global Resonances and Reactions

Although Open-RAN revenues are growing rapidly, this technology development still represents a very small proportion of the global RAN market. From technical and economic perspectives, it remains unclear whether the Open-RAN architecture will increase competition in the market as well as reduce the Total Cost of Ownership (TCO) of mobile network deployments. There is also a concern over the security issues and possible cyber-attacks when adopting the open/cloud native technology.

Czech conference chair serve as a set of recommendations and principles for nations to design, construct, and administer their 5G infrastructure. (U.S. Department of State, n.d)

⁷ The 5G Toolbox, released by the European Commission, provides definitions and measurements on how to avoid the use of "high-risk" suppliers in the network.

⁶ In May 2019, government officials from more than 30 countries across the globe, alongside representatives from the European Union, the North Atlantic Treaty Organization, and industry, participated in discussions regarding the important national security, economic, and commercial considerations that must be part of each country's evaluation of 5G vendors. The resulting Prague Proposals on 5G security published by the

Apart from being raised and discussed among the forums of technology industries, the Open-RAN has also been entered in the geopolitical arena. The Open-RAN model, in this sense, is an approach, driven by the United States, to replace a closed/old 5G architecture by breaking free from the limitations of bundle approach of network hardware manufacturers, occupied by Huawei and Chinese vendors.

In this section, the paper will be divided into two sub-section. The first one will discuss about the reaction of the two superpower (Washington and Beijing) regarding the newly architect of the Open-RAN. After that, the paper will analyze the reaction of international actors and countries. Public policy decision as well as industry's response on adopting the Open-RAN from different regions across the globe will also be described.

3.2.1 Reactions of Washington and Beijing

The high market share of Chinese tech giant Huawei in the global mobile infrastructure has become a critical concern in the Washington as well as the western countries. Critics raise a primary concerns on the security issues that critical 5G infrastructure, entrusted by companies from China, would be manipulated, disrupted or even controlled by the Chinese government. (Lee, Han, Zhu, 2022)

From Washington standpoint, the threats from Chinese firms (Huawei) on their 5G infrastructure has forced the U.S. leaders to replace Huawei equipment with the alternative technology. Several indicatives have been proposed, including the Open-RAN model. The new model presents an emancipatory technology that would allow network operators to break free from limitations of bundle approach of network hardware manufacturers, leveraging the competition and innovation in the network industry. (Plantin, 2021) However, from American leaders' stance, the Open-RAN will be a newly constructed term for "trust" and "transparency" technology, using to ban untrustworthy foreign gear and equipment. In 2020, Washington has endorsed the Open-RAN model and put it at the center of technology.

Washington' attempts to exclude Huawei from their networks has been politicalized and pushed to their allies through the Open RAN

Policy Coalition. The U.S. tech firms are extremely well represented in the coalition. Representatives from Japan, South Korea, Spain and the UK has joined, but no Chinese company is named and represented.

In the tech realm, it is hardly free of Chinese technology. The statement is clearly seen from the representatives and membership of Chinese tech firms in the O-RAN Alliance. O-RAN Alliance is a world-wide community of mobile operators, vendors, and research and academic institutions with the purpose to develop technical standards for the Open-RAN. It includes dozens of Chinese companies, including ZTE, China Mobile, China Telecom, and China Unicom. (Kennedy, 2023) The increasing role of Chinese tech companies in the Alliance could be presumed that in the near future, state-supported Chinese firms could become a leading Open-RAN supplier.

3.2.2 International Reactions

The Open-RAN technology was endorsed by Trump administration and was laid in the central strategy for Washington's tech policy. Washington has started exporting and lobbying the Open-RAN tech policy to its allied countries thought an Open RAN Policy Coalition. The international reactions towards the new Open-RAN tech are vary, depending upon costs, benefits and political pressures facing. In this section, the paper will discuss public policy decision as well as industry's response on adopting the Open-RAN from different regions across the globe.

(1) America region

In America region, Open-RAN deployments are still at an early stage. However, policy measures, supporting the Open-RAN, have started to emerge in a few countries, and interest among telecom industry is growing. The main reason is that North America consists of developed countries such as the U.S. and Canada, where they are expected to hold the largest share of the global Open-RAN market. The ecosystem of North America is highly advanced in technology, particularly in 5G, cloud, Machine Learning, and big data.

(1.1) Canada

o Government position

In December 2022, Canada, along with Australia, the UK and the U.S.,

issued a statement in support of telecommunications supplier diversity, and interoperable and open architectures. The Canadian government clearly stated that despite the benefits and economic opportunities of 5G, the technology will also introduce new security concerns that malicious actors could exploit.

The Government of Canada has serious concerns about suppliers such as Huawei and ZTE who could be compelled to comply with extrajudicial directions from foreign governments that would be detrimental to Canadian interests and would conflict with Canadian laws. In doing so, the Government of Canada has prohibited Canadian telecommunications service providers from deploying Huawei and ZTE products and services in their 5G networks.

Like the allies, Canada believes that the Government should be committed to maximizing the social and economic benefits of 5G and access to telecommunications services at large, but not at the expense of security. (Government of Canada, n.d)

- **Industry initiative**

The Operators, **Bell and Telus**, joined O-RAN Alliance and tended to support the Open-RAN technology. In April 2023, Bell participated an industry group to develop software-based Open-RAN architecture, while Telus is working on Open-RAN implementation and will require the vendors to support the Open-RAN. (Cullen, 2023)

(1.2) Brazil

- **Government position**

In May 2023, Brazil's Ministry of Science, Technology and Innovation (MCI) announced the investment of nearly \$36 million in the development of 5G and 6G towards a virtual environment and the Open-RAN. (Cullen, 2023)

The objective of the investment is to support the development of technology in the safer ways. Government believes that the increased range of suppliers and

disaggregation of network equipment would make the market more competitive.

Later in August 2023, Brazilian telecom regulator, Anatel, has signed an agreement with the Japanese government (Ministry of Internal Affairs and Communications of Japan (MIC)), focusing on the Open- RAN, with the goal of increasing deployments of the technology in Brazil.

- **Industry initiative**

Telefonica Vivo, One of telecom operator, conducted an Open-RAN technology-based trials for 4G and 5G in Brazil by using suppliers from Mavenir, NEC, and Rakuten. (Cullen, 2023) The trial is part of Telefonica's strategy to conduct Open-RAN trials across Germany, Spain, the United Kingdom, and Brazil (Kadia, 2024).

(2) Europe

There have been rising concerns in Europe that Chinese 5G RAN equipment may cause threats to data privacy and national security. As a result of this, the European Commission, in January 2020, has launched a "5G toolbox". The toolbox indirectly implies that the Chinese firms and operators are "high-risk- suppliers, but leaving the decision to each state to take their own risks for the provision of the 5G infrastructure.

Since the EU Toolbox was adopted, the topic of Open-RAN has received significant attention and interest. The rationale is rooted from the fact that the Open-RAN could facilitate the use of different suppliers in the RAN. This therefore complies with the implementation of 5G toolbox, which recommends the diversity of suppliers in order to avoid or limit any major dependency on a single supplier. However, since the Open-RAN technology is still at an early phase of maturity, the extent to which the associated security risk will occur is not clear. The EU Member States with the support of the European Commission and the EU Agency for Cybersecurity therefore have conducted a report to analyze cybersecurity implications of Open Radio Access Networks (RAN). The report has identified the possible security opportunities and risks of the Open-RAN and has made an initial guidance for state members

to carefully adjust their requirements at national level for their actual deployment in order to mitigate the risks associated with the Open-RAN networks. (European Commission, 2022)

For the telecom industry, giant network operators are very active to develop the Open-RAN networks. Telecom operators, consisting of Vodafone, Telefonica, TIM, Deutsche Telekom, and Orange, signed a memorandum of understanding (MoU) in 2021 to support the rollout of Open-RAN networks across Europe. Under the Open-RAN MoU, entitled ‘Progress Update on Maturity, Security and Energy Efficiency,’ operators will work closely with industry players to make Open-RAN become a technology of choice for future mobile networks by committing to create a maturity, security and energy efficient network. The ongoing process of adopting the Open-RAN can be summarized as follows: (Kadia, 2024)

- **Telefonica** is planning to

- (1) Trial an Open-RAN technology in 2020-2021.
- (2) Initial deployments in 2021-2022.
- (3) Deployments in Spain, Brazil, Germany, and the UK in 2022 and onwards.

- **Deutsche Telekom** plans to deploy Open-RAN technology in 2021 at 25 sites in Neubrandenburg, a city north of Berlin, in Germany. The key vendors of the Open-RAN include Mavenir, Fujitsu, NEC, Nokia, Dell, and others.

- **Orange** plans to deploy Open-RAN network equipment starting from 2025 and will conduct virtual and automated network trials by the end of 2024. From Orange’s standpoint, Open-RAN will provide opportunities to the new vendors, but not at the cost of Nokia and Ericsson.

- **Vodafone**, in 2020, has launched Open-RAN based 4G services at 30 locations in Ireland, in partnership with Parallel Wireless. It also has launched the first commercial Open-RAN 4G site in a rural area in Wales, the UK by partnership with Mavenir, Dell, Kontron, and Lime Microsystems. By 2023, Vodafone expects to use the Open-RAN Technology approximately 30% across Europe.

For state members, most European countries seems to be active to embrace the new tech architecture. The example of the Open-RAN momentum in Europe is as follows:

(2.1) United Kingdom

o **Government position**

The UK government is committed to building the security and resilience of critical network infrastructure by enhancing competition and innovation within the telecoms supply chain. As set out in the UK 5G Supply Chain Diversification Strategy and extensive engagement with governments and industry across the world, the UK government would be committed to accelerate the development and deployment of open interface architectures, such as Open-RAN.

In April 2022, the government published **the Open RAN Principles**, in which their principles are consistent with the 2021 Prague Proposals, The objective of the principles is to guide governments and industry over how best to support the maturation of Open-RAN to ensure that technology would deliver on its promise. (Open RAN principles, 2022)

The four principles are:

1. Open disaggregation:

by allowing elements of the RAN to be sourced from different suppliers and implemented in new ways.

2. Standards-based compliance:

by allowing all suppliers to test solutions in an open and neutral environment.

3. Demonstrated interoperability:

by ensuring disaggregated elements work together as a fully functional system.

4. Implementation neutrality:

by allowing suppliers to innovate and differentiate on the features and performance of their products.

o **Industry initiative**

In 2021, one of the UK’s biggest operators – **Vodafone**, launched the UK’s first 5G Open-RAN site. It is claimed to be the “first scaled Open-RAN project in Europe”. Vodafone aims to achieve the diversity within the supply chain and enable the innovation in telecom sector. (Vodafone Press Office, 2022). In the first site installation (FSI), technologies used within the network came

from different vendors, namely Samsung, Dell, Intel technologies, and Wind River Studio. In 2022, Vodafone announced to expand its Open-RAN deployment to the urban area, which is considered to be the first deployment of Open-RAN in urban area in Europe. (Vodafone Press Office, 2022)

(2.2) Germany

○ Government position

In 2021, Germany's Federal Ministry of Transport and Digital Infrastructure provided 300 million euros in funding to develop the lab to test Open-RAN technology in the country. The lab will focus on disaggregated network solutions, such as Open-RAN, which is a new approach to build radio access networks by disaggregating hardware and software.

From Germany's standpoint, the funding aimed to advance the development and testing of O-RAN network technology in Germany and to support the establishment of its own and independent manufacturing industry. In the lab, all interested market participants have access and can work together across the board and learn from each-other regardless of whether they are network operators, network suppliers, or new players such as startups or SMEs. (Tomás, 2021)

○ Industry initiative

At the end of 2022, Germany announced its first launch of Open-RAN system that "based solely on the cloud" (1&1,2023) deployment. The operators driving this launch aimed to provide full Open-RAN network to utilize the 5G technology. The network operators has selected technologies from different vendors from different countries namely America, Europe and Asia and Pacific, such as Dell, Supermicro, Cisco, Rakuten, Mavenir ,Altiostar, and NEC.

(3) Asia-pacific

The Open-RAN market has experienced a rapid growth in Asia-Pacific region due to the increasing demand for cost-effective and flexible network solutions. Governments and telecom operators in Asia-Pacific are keen on adopting Open-RAN to address connectivity challenges, enhance network efficiency, and promote vendor diversification. The growing of the Open-RAN technology in the region could be somehow driven by the U.S. tech diplomacy. The Asia Open-RAN Academy, supported by the U.S. government, has been launched across the Indo-Pacific region. The academy will partner with governments, businesses, and civil society across the Indo-Pacific region, including Japan's Ministry of Internal Affairs and Communications and leading global telecommunications companies, such as Fujitsu, NEC, NTT DOCOMO, and Rakuten Symphony, to promote and enhance knowledge and accessibility of the Open-RAN. President Jo Biden has committed to expand the Asia Open-RAN Academy during his visit to Japan in May 2022, stating that Open-RAN will lower costs by increasing supplier diversity and competition (U.S. Mission Japan, 2022).

(3.1) Australia

○ Government position

In 2022, Australia, together with The U.S and Canada, have supported the UK's plans for ensuring the resilience and security of global telecoms supply chains and future 6G networks. They mutually have agreed to endorse the UK's plans for the development of Open-RAN, which allows providers to 'mix and match' solutions from multiple vendors.

However, in May 2023, Australian Department of the Prime Minister and Cabinet published "Open RAN Security Report", concluded that the use of Open-RAN does not fundamentally alter the security risk landscape for telecommunications, compared to more traditional RAN. From the report, risks and vulnerabilities of the Open-RAN could be stemming from utilization of cloud-based infrastructure which is increasing the tendency of network "attack surface". Diversification of suppliers and technology

components may also make it more difficult to keep track of all software in use in deployments. The report strongly recommended that Open-RAN stakeholders should also consider utilizing widely adopted industry standards and best practices, as well as conduct security checks on equipment. (Australian Department of the Prime Minister and Cabinet, 2023)

- **Industry initiative**

Telstra, Australia's largest mobile network, has partnered with Ericsson to launch Cloud RAN technology for commercial 5G network in 2023. As part of this deployment, Telstra and Ericsson have migrated two carrier frequencies 2600MHz and 3600MHz to the Cloud RAN infrastructure. The first sites of are located on the Gold Coast, Queensland (Ericsson, 2023).

Optus, Australia's second largest mobile operator, has deployed Open-RAN solution, using service from Parallel Wireless for providing 4G based mobile connectivity for its customers in remote region (Kadia, 2024).

(3.2) India

- **Government position**

Under the U.S. - India Comprehensive Global and Strategic Partnership, President Jo Biden and Prime Minister Modi, in 2023, shared a vision of creating secure and trusted telecommunications, resilient supply chains, and enabling global digital inclusion. To fulfill this vision, the two leaders launched two Joint Task Forces on advanced telecommunications, focusing on Open-RAN and research and development in 5G/6G technologies. Public-private cooperation between vendors and operators will be led by India's Bharat 6G Alliance and the U.S. Next G Alliance. (The White House Press Release, 2023)

The establishment of Joint Task Forces underscores the commitment between these two countries for Open-RAN collaboration.

- **Industry initiative**

Airtel, India's largest integrated telecommunications services provider, is a part of the O-RAN Alliance and Telecom Infra Project (TIP) and is contributing actively to the standardization efforts. (Kadia, 2024)

Earlier in 2021, Airtel partnered with Qualcomm to deliver 5G Fixed Wireless Access (FWA) to deliver broadband connectivity. Airtel will also utilize Qualcomm's Open-RAN platform via its network of vendors and device partners. (Kadia, 2024)

In 2023, it was announced that Airtel collaborated with Mavenir to deploy 5G Open-RAN sites. The initial plan is to deploy around 2,500 sites on Open-RAN with the aim to reach 10,000 sites in the future. (Khan, 2023)

Reliance Jio, an Indian telecom company, is building its own 5G network based on Open-RAN technology. Some of the companies that could potentially be part of the Jio 5G ecosystem include SignalChip, Saankhya Labs, Tejas Networks, Sterlite Technologies, and VVDN Technologies. (Kadia, 2024)

(3.3) Japan

- **Government position**

On August 18, 2023, leaders from Japan (Prime Minister Kishida), the Republic of Korea (President Yoon), and the U.S. (President Jo Biden) assembled at Camp David to discuss a range of strategic matters. Among them was the commitment to expand trilateral cooperation on the Open-RAN. This international collaboration seeks to promote Open-RAN solutions, fostering innovation and interoperability among nations. Their objective is to focus on space security cooperation and AI governance which are in line with the democratic values. (The White House, 2023)

In practice, Japanese government, led by Ministry of Internal Affairs and Communications (MIC), has set up action plan towards 2025. One of priority areas

include the promotion of Open-RAN technology as well as extending the technology cooperation under the Open-RAN initiative to various regions across the globe. For example (MIC, 2022):

- *In South-East Asia*, MIC will actively support surveys, workshops, and pilot initiatives to gain a deeper understanding of the need for open 5G.
- *In Oceania*, MIC will establish a Japan-Australia policy dialogue framework in the ICT field by strengthening networks in Australia via trials of 5G using Open-RAN. The aim of policy is to create more resilient mobile communications networks and establish multiple lines with the aim of securing redundancy in submarine telecommunications cables in Pacific Island nations and other third-party countries.
- *In North America*, MIC will encourage Japan-U.S. collaboration in many areas including the promotion of Open-RAN and other safe, open 5G networks, and investment in research, development, trial, and popularization of advanced ICT and safe networks such as 5G and Beyond 5G.
- *In Latin America*, MIC will empower Japan and the U.S.'s collaborative relationships with third-party countries while consulting with Latin American governments, such as in Brazil, regarding 5G and Open-RAN in particular.

- **Industry initiative**

In 2020, **NTT DOCOMO**, one of the largest Japanese telecom operator, expanded their lineup of 5G base stations using the Open-RAN technology. The multi-vendor interoperability project was developed by NEC and Samsung Electronics. (NTT DOCOMO, 2020).

In 2023, **KDDI Corporation** announced that it will start commercial deployment of 5G Open vRAN sites in Japan in collaboration with Samsung Electronics and Fujitsu Limited. Sites

consist of general-purpose server equipment and can be used with all 5G smartphones. Full scale development planned to start in 2024. (Fujitsu, 2023)

Rakuten Mobile has launched 4G and 5G commercial services based on Open-RAN architecture in Japan. The key vendors of deployments include AltioStar, Cisco, Nokia, Intel, IBM Red Hat, OKI, Fujitsu, Ciena, NEC, Qualcomm, Mavenir, Quanta Cloud Technology, Sercomm, Tech Mahindra, Allot, Innoeye, Viavi, Robin.io, Radcom, and Airspan.

Rakuten has also signed separate MoUs with NEC and Fujitsu to develop Open-RAN solutions for the global market. Rakuten has collaborated with more than 5 operators to develop a blueprint of Open RAN deployments. For example:

- Telefonica signed an agreement with Rakuten Mobile in September 2020 for research and lab trials supporting the Open-RAN architecture.
- Saudi Telecom Company (STC) and Etisalat Group signed MoU with Rakuten in December 2020 and January 2021 respectively, to develop a reference blueprint for mobile broadband networks and Open-RAN technology.

(3.4) South Korea

- **Government position**

The joint statement between the leaders of the U.S. (President Jo Biden) and South Korea (President Yoon) was released in May 2021. The cooperation between the two parties regarding development of 5G and 6G using Open-RAN was clearly stated. It aims to tackle the security and diversity of vendors issues in telecommunication infrastructure in the hope that both parties will achieve “open, transparent, and efficient 5G and 6G network” (The White House, 2021). Moreover, in 2022, South Korea together with the UK government announced their cooperation in research investment to develop and foster 5G Open-RAN adoption. (Department for Digital, Culture,

Media & Sport, 2022)

In practice, since 2020 South Korea has started the working group in a form of public-private partnership. This working group aims to drive the adoption and commercialize 5G Open-RAN and its ecosystem within the country. Later in 2023, the Ministry of Science and ICT has also launched the official public-private partnership in expanding the Open-RAN Testbeds and global demonstration projects. This partnership included various leading companies in telecommunications technology industry, such as SK Telecom, KT, LG U+, LG Electronics, and Samsung Electronics. (Ministry of Science and ICT, 2023)

- **Industry initiative**

SK Telecom, in 2023, has successfully completed its first Open-RAN technical Test with 5 participating companies, including Korean national research institute (ETRI), domestic (HFR) and global vendors (Hewlett Packard Enterprise, Intel, Keysight Technologies). Activities were focused on evaluation of Open-RAN based 5G systems.

In 2023, **KT**, together with NTT Docomo, Fujitsu, SOLiD, Keysight Technologies and Electronics and Telecommunications Research Institute (ETRI), have successfully conducted an interoperability test using virtualized Open-RAN in South Korea.

(3.5) Singapore

- **Government position**

Open-RAN has Singapore full attention around 2023, it was clearly stated in Singapore Digital Connectivity Blueprint or DCB that Singapore will develop 5G and 6G using Open-RAN architecture in order to “build capabilities in emerging and future communications technologies” (Infocomm Media Development Authority, 2023).

- **Industry initiative**

In line with the DCB, Singapore University of Technology and Design announced its first Open Testing and

Integration Centre (OTIC) of Open-RAN at the Mobile World Congress Barcelona (MWC) 2023. The project was funded by the IMDA through Future Communications R&D Programme. (Singapore University of Technology and Design, 2023)

(3.6) Indonesia

- **Government position**

In 2018, Indonesia launched “Making Indonesia 4.0” as a country roadmap, aiming to push Indonesia to the fourth industrial revolution. In order to achieve the goal, infrastructure and connectivity is one of the biggest challenges that government has to overcome. (Indonesia Investments, 2018)

Open-RAN, then, came into the scene as one of the possible solutions to achieve lower cost of network deployment. Therefore, in 2020, the Indonesian government together with Telkom University launched the Telecom Infra Project (TIP) Community Lab to enable the development in 5G network and the improvement in connectivity in Indonesia. (Telkom University, 2020)

In January 2024, Ministry of Communication and Information began a study to evaluate the feasibility of deploying the Open-RAN in 1,621 villages, lacking mobile coverage, in a project funded by the U.S. Trade and Development Agency or USTDA (Dou, 2024).

- **Industry initiative**

In Indonesia, Open-RAN is strongly supported by its cellular operators. For example:

- **Indosat Ooredoo**, a cellular operator in Indonesia, conducted Open-RAN field trials, including proof of concept and functional testing in April 2021. The field trials were carried out in several locations in the Maluku region. The trials were supported by TIP Open-RAN Project Group and Parallel Wireless. (Kadia, 2024)

- **XL Axiata** has also started testing Open-RAN in Eastern Indonesia in 2021.

All cellular operators join the Open RAN Lab Community consisting of Telecom Infra Project (TIP), GSM Association, Government of Indonesia, and Tel-U (Telkom University) with the strong purpose of growing digital talent and a diverse telecommunications ecosystem. (Telecom Infra Project, 2021)

(3.7) The Philippines

- **Government position**

In June 2022, the U.S. Agency for International Development (USAID) launched the Asia Open-RAN Academy in partnership with Japan's government to expand the Open-RAN technology in the region. The academy has trained and educated over 15,000 engineers and policymakers in the Philippines. (Dou, 2024)

- **Industry initiative**

In February 2024, **NOW Telecom Company**, Inc. ("NOW Telecom") and Rakuten Symphony signed a Memorandum of Understanding (MoU) to establish a collaborative framework for pilot deployment of a 5G Open-RAN in the Philippines.

NOW Telecom is a privately held mobile telephony licensee holder in the Philippines. In November 2022, the United States government acting through the U.S. Trade and Development Agency (USTDA), announced its partnership with NOW Telecom in deploying 5G technologies and a nationwide broadband network in the Philippines (Rakuten, 2024).

(4) Middle-East

The telecom sectors in the Middle-East Region is active to participate in the newly Open-RAN technology. The giant telecom operators, such as STC, Etihad Etisalat (Mobily), Zain, Batelco, and Omantel, has set up "the Middle East Open Radio Access Network (ORAN) consortium" and has mutually launched the first Open-RAN whitepaper with the aim

to accelerate the development of open network technologies in the region.

In the whitepaper, the operators have highlighted the recent efforts, ranging from field trials, lab establishments, vendor interactions, and organizations' engagements to verify and explore the ecosystem and readiness for the Open-RAN use cases.

(4.1) Saudi Arabia

- **Government position**

The Memorandum of Understanding (MoU) between Saudi Arabia and the U.S. regarding the cooperation in 5G and 6G development using Open-RAN architecture was signed in 2022. This MoU aims to foster the deployment of Open-RAN network in 5G and focus more on R&D of 6G technology. The developed network will be used as the digital economy booster in Saudi Arabia as well as will secure the position as technology and innovation leader in the region. (Ministry of Communications and Information Technology, 2022)

Even though there is the MoU between the U.S. and Saudi leaders, the policy regarding Open-RAN from the Saudi government remains unclear. Most initiative concerning the open architecture rather came from private sector. The key initiative within the Middle-East region is "the Gulf Open-RAN initiative", which has been launched by telecoms operators across region. The initiative has been rooted under the geopolitical climate and technology de-coupling between the U.S and China. (Soliman, 2022)

- **Industry initiative**

Etihad Etisalat (Mobily), in 2024, have signed MoU with Ericsson to enhance and develop the Open-RAN network in Saudi Arabia with a focus on boosting the network's flexibility. The scope of the MoU covers network segmentation between the purpose-built RAN and Cloud RAN as well as the identification of potential locations where Cloud RAN deployment would be most beneficial (Ericsson, 2024).

In February 2024, **STC**, the leading enabler of digital transformation in Saudi Arabia, has signed an Open-RAN agreement with Mavenir, the cloud-native network infrastructure provider, to launch the first commercial Open-RAN network in Saudi Arabia. The strategic mission is to deliver emerging technology to mobile customers, supporting the Vision 2030 digital transformation strategy (Mavenir, 2024).

It can be seen clearly that although the Open-RAN trends and revenues are growing significantly, the number still represent a very small proportion of the global RAN market. It also remains unclear whether the Open-RAN architecture will increase the competition, will reduce the Total Cost of Ownership of mobile networks or will increase the security of the connection. However, operators, tech-policymakers, and governments around the world have reacted to the new tech architecture differently.

Government and telecom industry in America, such as the U.S. and Brazil, in Europe such as UK and Germany, and in Asia-Pacific such as Australia, Japan, and India, has strongly engaged in the Open-RAN technology. Open-RAN has become a forefront of their strategies, although specific measures to promote the adoption of open RAN has varied.

The rationale behind the Open-RAN policies of these countries are beyond the technological and economic values. The new tech has been politicalized and has enter the geopolitical arena. It could not be denied that the U.S. government has exported the concept of “openness and trustworthiness” of technology and has promoted it globally, especially through its allies in different regions, by using the terms of “Open-RAN”. The joint statement between leaders has been announced to commit to the expansion of the newly open architect to counter back the traditional model, led by the Chinese firms. In developing countries, especially in the South-East Asia region, such as in Indonesia and in the Philippines, the propaganda of tech polices is managed in the form of aid and subsidization.

Other governments, including some countries in Asia and in Middle East, has chosen a more neutral approach by leaving an open-RAN adoption to industry players.

4. Open-RAN: Perspectives from Industry and Regulator

In order to gather an in-depth information regarding the Open-RAN in terms of technical, economic and geopolitics context, interviews have been conducted from sector’s stakeholders such as global tech vendors, local telecom operators, telecom regulators as well as tech academia. The Open-RAN, from industry and regulator perspective, offers both the pros and the cons depending on the context of deployment, utilization as well as political and economic climate. The Summaries of the finding can be seen as follows:

4.1 Global vendors

The global vendors have shared their views towards the newly constructed Open-RAN. Their perspectives are centered at the issues of trusted network as well as the variety of the vendor. The detail is discussed here as follows:

4.1.1 Trusted Network

By enabling multi-vendor approaches and interoperability, Open-RAN frees operators from vendor lock-in and empowers them to choose technologies that best suit their needs. However, in the development of the Open-RAN, there are a strong concern over the issue of network transparency. The U.S., along with its allies such as the European Union and Japan, have emphasized the security risks associated with closed network systems, particularly in base stations due to the lack of third-party oversight. This concern has driven the need for co-developed security standards with an independent verification, focusing on trusted networks.

From the industry’s point of views, while cost reduction through vendor competition remains a key advantage of the Open-RAN, its core value lies in fostering “**trusted networks**”. This concept encompasses security, transparency, and the reliability of network equipment (both in hardware and software) and personnel.

As the U.S. and its allies emphasize secure networks, failure to adopt this approach could lead to international trade barriers. In this sense, to accelerate 5G network, governments and regulators have to prioritize “**building trusted networks**” in the center of their tech policies.

4.1.2 New Vendors with Variety

Open-RAN disrupts the telecom vendor landscape by lowering the barrier to entry for new players. This reduction in entry barriers fosters innovation and diversification within the ecosystem. Network operators, in this regard, benefit from a wider range of solutions, potentially at lower costs.

Furthermore, the inherent interoperability of Open-RAN, encompassing both hardware and software components, opens the door for new entrants from diverse industries. This extends beyond traditional network equipment providers, allowing software and service companies to contribute to enhanced network efficiency. Open-RAN architecture presents a fertile ground for innovation, particularly in the areas of artificial intelligence and machine learning. These advancements could further optimize interoperability and network performance.

The influx of new players, across hardware and software, presents a unique opportunity for industry restructuring. Established network equipment providers may face competition not only from traditional rivals but also from entirely new players from different industries. This has the potential to reshape the vendor landscape, fostering a more competitive and potentially more innovative environment within the telecommunications sector. New vendors joining the scene can be divided into nine categories, which are:

- **Equipment & Infrastructure:**
Compliant hardware and software such as base stations, radios, software-defined radios, virtualized network functions (VNFs).
- **Network Integration:**
Businesses offer design, deployment, and integration services for Open-RAN solutions, ensuring interoperability and performance.
- **Managed Services:**
Providers handle network operations, maintenance, monitoring, and troubleshooting for Open-RAN networks.
- **Software Development:**
Businesses develop virtualized network functions (VNFs) for network slicing, optimization, security, and analytics within Open-RAN environments.

- **Consulting & Training:**

Experts provide consulting and training services to help organizations understand and transition to Open-RAN technologies.

- **Testing & Validation:**

Independent services ensure seamless integration, adherence to standards, and promised performance of Open-RAN components.

- **Investment & Funding:**

Opportunities exist for investors in the start-ups and companies developing innovative Open-RAN solutions and business models.

- **R&D:**

Continuous research focuses on improving performance, efficiency, and security of Open-RAN components.

- **Ecosystem Support:**

Organizations can build communities and platforms fostering information sharing, knowledge exchange, and collaboration within the Open-RAN ecosystem.

Throughout the interview, vendors have suggested that in a case of Thailand, the initial adoption of Open-RAN might be more feasible at the software and service level, rather than the infrastructure level. This approach offers a lower initial investment compared to a complete network overhaul. Proactive government and regulatory bodies can also play a crucial role in facilitating this initial adoption by establishing a set of clear standard which helps ensuring a smooth interoperability between various software and service components, ultimately contributing to an optimal network performance.

4.2 Possible users: Telecom operators

While the vendors tends to push forwards the advantages of using Open-RAN and its open interface, the telecom operators in Thailand seems to be reluctant to adopt the new technology. From their perspective, it is undeniable that the open standard of the Open-RAN will facilitate the new vendors into the market, however, the benefit of having multi-vendors approach in the network still be somewhat questionable.

The telecom operators argued that it would be difficult for them to adopt the Open-RAN into their network. The main reasons are coming from the concern regarding:

- **The compatibility with the existing infrastructure**

One significant challenge to the adoption of Open-RAN in Thailand stems from the existing network infrastructure of some telecom operators. Operators have already significantly invested in a core network equipment from specific vendors, including Huawei. Huawei has not yet indicated any intention of adhering to open concept of the Open-RAN standards. This incompatibility creates a barrier to integrate Open-RAN technology with the existing infrastructure. The replacement of all network equipment by adopting the Open-RAN would yield a high cost to the operators.

- **The cost of OPEX, and other operation and maintenance challenges**

While the possibility of utilizing Open-RAN in future network roll-out exists, Thai telecom operators remain hesitant to embrace a multi-vendor approach. Some local operators have expressed concerns regarding the increased complexity of network management. This means introducing equipment from multiple vendors could lead to communication challenges during maintenance due to the involvement of various parties. This multi-vendor environment could also contribute to a rise in overall operational expenditures (OPEX) in the long run.

4.3 Regulator and academia

The emergence of Open-RAN has been attributed to a geopolitical tension between the U.S. and China. Some regulators and academics have believed that the Open-RAN is a “constructed open standard”, championed by the U.S. and its allies, with the main purpose to encounter the dominance of Chinese players in the telecom equipment market.

From academic and regulatory standpoint, the open standard introduced by the Open-RAN technology may not be necessary considering the fact

that 3GPP⁸ has already existed as the interoperability standard for telecommunications. However, it is very important to acknowledge that existing 3GPP standard has limitation due to market competition and regulatory compliance.

Regarding the cost implications, while Open-RAN may reduce capital expenditure (Capex) in the long run, the potential for increased operational expenditure (Opex) could not be ignored. The complexity of managing multiple vendors within an Open-RAN network could lead to a higher maintenance cost, staff training expenses, and unforeseen technical challenges.

The adoption of Open-RAN in Thailand faces potential hurdles. The existing telecommunications infrastructure, primarily built by Chinese vendors, may hinder the transition. However, geopolitical considerations add another layer of complexity. The increasing emphasis on “trusted networks” within international trade agreements (FTAs) demands Thai government and related regulators to reshape their network security. Open-RAN, in this regards, may offer an opportunity to address this type of concern.

Amidst the rise of newly tech-architect offered by the Open-RAN, telecom regulator could facilitate the adoption by granting network operators greater freedom in vendor selection and management. This approach, however, should go hand in hand with the implementation of robust security standard. The security standard could possibly be enforced to network operators through additional obligations under telecom licenses or through security guidelines for building trusted network. This balanced approach could foster innovation, ensure network security, while balancing the pressure from geopolitical landscape.

5. Conclusion and Recommendations

As many countries have laid the 5G network as a backbone of ICT infrastructure, there have been rising concerns regarding the spread of Chinese 5G equipment that may cause threats to data privacy, economic competitiveness, and national security. It has been believed that such equipment may be used for state espionage.

⁸ The 3rd Generation Partnership Project (3GPP) unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as “Organizational Partners”, for providing

their members with a stable environment to produce technology Specifications. 3GPP specifications cover cellular telecommunications technologies, including radio access, core network and service capabilities.

(Rosenberger, 2020) With the spread of concerns over Chinese/Huawei's 5G equipment, the Open-RAN architect has been emerged as a solution to achieve security and resilience of 5G infrastructure.

From technical aspect, the disaggregation and virtualization of the Open-RAN enables flexible deployments and increase the resiliency of network configuration. The open interface of the new architect also allows operators to use different equipment from different vendors. These technical advantage therefore pave the way for network operators to achieve economic gains.

From economic point of views, the Open-RAN architect will open the ecosystem to the competition, allowing new players to offers services, create more choices, as well as reduce Total Cost of Ownership.

Upon the emergence of the new Open-RAN, the United States is extremely active in facilitating the development and expanding the adoption in the global tech industry. The U.S. leaders has expected that the Open-RAN could change the backdrop of 5G technology by increasing its competitiveness while reducing the dominant power of Chinese in the 5G tech realm.

Regarding the Washington's interest behind the Open-RAN, this paper presume that Open-RAN Technology is somehow a political discourse constructed by the U.S. government to ban Chinese technology. **From the geopolitics dimension**, the Open-RAN is not a new technological race; however, it could be a testament of how American ban Chinese (Huawei) gears and equipment from 5G network by creating a tech symbolic that stands the value of freedom, openness, trustworthy and democracy.

Until now, it is still unclear whether the Open-RAN architecture will increase the competition, reduce the cost or increase the security of the connection. However, operators, tech -policymakers, and governments around the world have reacted to the new tech architecture differently. The clear example can be seen in the U.S. closed allies, such as the United Kingdom, Germany, Australia, Japan, India, and South Korea. These countries have strongly engaged in the Open-RAN and have put the Open-RAN as a center of their technology strategies. The expansion of the U.S. tech propaganda over "openness and trustworthiness" can also be seen in the form of aids and

subsidization. The Open-RAN lab, research, and engineer training have been introduced by the U.S. agencies in countries such as in Indonesia and the Philippines. However, among the geopolitics pressure, some countries have remained neutral in their tech approach by leaving the decision on the open-RAN adoption to players in the industry.

According to an in-depth information gathering from sector's stakeholders, while Open-RAN could reduce cost by increasing players and vendor competition, and foster innovation and diversification, there is a strong concern over network transparency. This limitation demands the need to build what we called "**trusted network**." This concept encompasses security, transparency, and the reliability of network equipment both in hardware and software as well as personnel.

In case of Thailand, the adoption of Open-RAN technology may be hindered by the fact that local operators have already significantly invested in a core network equipment from specific vendors, including Huawei. The replacement of all network equipment by adopting the Open-RAN would yield a high cost to the operators. Based on these limitations, this paper recommends that the initial adoption of Open-RAN might be more feasible at the software and service level. Operators, in this regard, could take their own decisions over who to partner for the provision of technology. This approach allows market to work for itself while offering a lower initial investment, compared to a complete network infrastructure.

Unlike traditional/closed network architectures, Open-RAN thrives on an open ecosystem at different level of the network. This openness fosters innovation by allowing a wider range of companies to develop different products, including software and services. However, **from regulator perspective**, the openness characteristic of the new architect has become a cause of concern. The reason is rooted from the fact that the new players are not bound by the existing regulatory framework, making their products or services fall outside current regulations. Without regulatory framework or guideline in place, it could lead to unforeseen security vulnerabilities. The concern ultimately highlights the need for robust security standard.

Considering the geopolitical dimension, this paper will emphasize the need to build the

"trusted networks". Thai government and related telecom regulators, in this sense, have to reshape and prioritized their network security policies. The security standard could possibly be enforced to network operators through additional obligations under telecom licenses or through the establishment of security guidelines on trusted network. The proposed approach could foster innovation, ensure network security, while balancing the pressure from geopolitical landscape.

References

- Çekinmez, F. (2023, July). *Radio Access Network (RAN)*. Retrieved from Medium: <https://medium.com/@fthcknmz/radio-access-network-ran-1fb033b708f1>
- Chakraborty, D. (2024, January). *Exploring the evolution and potential of Open RAN*. Retrieved from GSMA: <https://www.gsma.com/asia-pacific/blog/apacpg/open-ran/>
- Claydon, P. (2021, March). *A brief history of Open RAN*. Retrieved from Tech UK: <https://www.techuk.org/resource/a-brief-history-of-open-ran.html>
- Craven, C. (n.d.). *What Are the Open RAN Benefits and Challenges?* Retrieved from sdxcentral: <https://www.sdxcentral.com/5g/ran/definitions/what-is-open-ran-radio-access-network/what-are-open-ran-benefits-challenges/>
- de Geest, G., Grundin, G., & Vetvik, O. J. (2023, February). *Telecom networks: Tracking the coming xRAN revolution*. Retrieved from McKinsey & Company: <https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/telecom-networks-tracking-the-coming-xran-revolution>
- Department for Digital, Culture, Media & Sport and Department for Science, Innovation & Technology. (2022, April). *Open RAN principles*. Retrieved from GOV.UK: <https://www.gov.uk/government/publications/uk-open-ran-principles/open-ran-principles>
- Department for Digital, Culture, Media & Sport. (2022, July). *New government plans to fire up innovation in 5G and 6G as UK and South Korea launch telecoms technology partnership*. Retrieved from GOV.UK: <https://www.gov.uk/government/news/new-government-plans-to-fire-up-innovation-in-5g-and-6g-as-uk-and-south-korea-launch-telecoms-technology-partnership>
- 6g-as-uk-and-south-korea-launch-telecoms-technology-partnership
- Dou, E. (2024, February). *Trump dreamt of a 'Huawei killer.' Biden is trying to unleash it*. Retrieved from The Washington Post: <https://www.washingtonpost.com/technology/2024/02/12/oran-biden-china-huawei-technology/>
- Ericsson. (2023, July). *Telstra commercial 5G sites go live with Ericsson Cloud RAN technology*. Retrieved from Ericsson: <https://www.ericsson.com/en/press-releases/7/2023/telstra-commercial-5g-sites-go-live-with-ericsson-cloud-ran-technology>
- Ericsson. (2024, March). *Ericsson and Mobily evolve network in Saudi Arabia with Open RAN*. Retrieved from <https://www.ericsson.com/en/press-releases/5/2024/ericsson-and-mobily-evolve-network-in-saudi-arabia-with-open-ran>: <https://www.ericsson.com/en/press-releases/5/2024/ericsson-and-mobily-evolve-network-in-saudi-arabia-with-open-ran>
- European Commission. (2022, May). *Cybersecurity of 5G networks: EU publishes report on the security of Open RAN*. Retrieved from European Commission: <https://digital-strategy.ec.europa.eu/en/news/cybersecurity-5g-networks-eu-publishes-report-security-open-ran>
- Faisal. (2021, April). *C-RAN vs Cloud RAN vs vRAN vs O-RAN vs traditional RAN- Guide!* Retrieved from Telco Cloud Bridge: <https://telcocloudbridge.com/blog/c-ran-vs-cloud-ran-vs-vran-vs-o-ran/>
- Fujitsu. (2023, January). *KDDI starts commercial deployment of 5G Open vRAN sites in Japan in collaboration with Samsung Electronics and Fujitsu Limited*. Retrieved from Fujitsu: <https://www.fujitsu.com/global/about/resources/news/press-releases/2023/0124-01.html>
- Government of Canada. (n.d.). *Policy Statement – Securing Canada's Telecommunications System*. Retrieved from Government of Canada: <https://www.canada.ca/en/innovation-science-economic-development/news/2022/05/policy-statement--securing-canadas-telecommunications-system.html>
- Indonesia Investments. (2018, April). *Widodo Launches Roadmap for Industry 4.0: "Making Indonesia 4.0"*. Retrieved from Indonesia

- Investments: <https://www.indonesia-investments.com/business/business-columns/widodo-launches-roadmap-for-industry-4.0-making-indonesia-4.0/item8711>
- Infocomm Media Development Authority. (2019, May). *The second consultation paper regarding Mobile Services and Networks*. Retrieved from Infocomm Media Development Authority: <https://www.imda.gov.sg/-/media/Imda/Files/Regulation-Licensing-and-Consultations/Consultations/Consultation-Papers/Second-Public-Consultation-on-5G-Mobile-Services-and-Networks/Second-5G-Public-Consultation-7-May-2019-Final.pdf>
- Infocomm Media Development Authority. (2023, August). *Singapore's Digital Connectivity Blueprint*. Retrieved from Infocomm Media Development Authority: <https://www.imda.gov.sg/-/media/imda/files/programme/digital-connectivity-blueprint/digital-connectivity-blueprint-report.pdf>
- Inkster, N., Weinstein, E. S., & Lee, J. (2022, September 1). *Ask the Experts: Is China's Semiconductor Strategy Working?* Retrieved from LSE Blog: <https://blogs.lse.ac.uk/cff/2022/09/01/is-chinas-semiconductor-strategy-working/>
- Juniper Network. (n.d.). *What Is a RAN Intelligent Controller (RIC)?* Retrieved from Juniper Network: <https://www.juniper.net/us/en/research-topics/what-is-ric.html#:~:text=A%20RAN%20Intelligent%20controller%20%28RIC%29%20is%20a%20software-defined,that%E2%80%99s%20responsible%20for%20controlling%20and%20optimizing%20RAN%20functions.>
- Kadia, H. (2024, March). *CURRENT STATE OF OPEN RAN – COUNTRIES & OPERATORS DEPLOYING & TRIALING OPEN RAN*. Retrieved from TeckNexus: <https://tecknexus.com/5g-network/5g-magazine-open-ran-june-2021/current-state-of-open-ran-countries-operators-deploying-trialing-open-ran/>
- Kennedy, A. (2023, August). *Confronting China's tech challenge requires resilience*. Retrieved from East Asia Forum: <https://eastasiaforum.org/2023/08/12/confronting-chinas-tech-challenge-requires-resilience/>
- Lee-Makiyama, H., & Forsthuber, F. (2020). Open RAN: The Technology, its Politics and Europe's Response. In *European Centre for International Political Economy*. <https://ecipe.org/publications/open-ran-europes-response/>
- Markets And Markets. (2022, December). *Open Radio Access Network (Open RAN) Market by Component (Hardware, Software, Services), Type (Open RAN RU, Open vRAN), Frequency (Sub-6GHz, mmWave), Radio Interface, Access (Public, Private), Network and Region - Global Forecast to 2027*. Retrieved from Markets And Markets: <https://www.marketsandmarkets.com/Market-Reports/open-ran-market-153445936.html>
- Mavenir. (2024, February). *solutions by stc Signs an Open RAN Agreement with Mavenir to Launch First Commercial Open RAN in Saudi Arabia*. Retrieved from Mavenir: <https://www.mavenir.com/press-releases/solutions-by-stc-signs-an-open-ran-agreement-with-mavenir-to-launch-first-commercial-open-ran-in-saudi-arabia/>
- MIC. (2022, July). *Summary of MIC's Global Promotion Action Plan 2025*. Retrieved from MIC: https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Summary_of_MIC's_Global_Promotion_Action_Plan_2025.pdf
- Ministry of Communications and Information Technology. (2022, July). *Saudi Arabia and USA Ink Partnership Agreement in 5G and 6G Technologies*. Retrieved from Ministry of Communications and Information Technology: <https://www.mcit.gov.sa/en/news/saudi-arabia-and-usa-ink-partnership-agreement-5g-and-6g-technologies>
- Ministry of Science and ICT. (2023). *Public-private cooperation for entry into the global open RAN market*. Retrieved from Ministry of Science and ICT: <https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=2&bbsSeqNo=42&nttSeqNo=851&searchOpt=ALL&searchTxt=>
- Ministry of Science and ICT. (2023). *Public-private cooperation for entry into the global open RAN market*. Retrieved from Ministry of Science and ICT: <https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=2&bbsSeqNo=42&nttSeqNo=851&searchOpt=ALL&searchTxt=>
- Nestoras, A., & Cappelletti, F. (2021). 5G Geopolitics and European Strategic Autonomy: Security, Standardisation, and the (False?)

- Promise of Open RAN. *Future Europe Journal*, (1), 9.
- Nocetti, J. (2022). *Europe and the Geopolitics of 5G: Walking a Technological Tightrope*.
- Nokia Communication. (n.d.). *Update: Open RAN explained*. Retrieved from Nokia: <https://www.nokia.com/about-us/newsroom/articles/open-ran-explained/>
- Open RAN Policy Coalition. (2024, January). *Our Mission*. Retrieved from Open RAN Policy Coalition: <https://www.openranpolicy.org/>
- Oyama, T., & Okabe, H. (2023). *Open RAN will change the future of the telecom industry*. https://www.ey.com/en_jp/tmt/open-ran-will-change-the-future-of-the-telecom-industry
- Pankajakshan, B. (2022, June). *The Role Of Open RAN In Helping Open Markets And Unlocking The Value Of 5G*. Retrieved from Mavenir: <https://www.mavenir.com/blog/the-role-of-open-ran-in-helping-open-markets-and-unlocking-the-value-of-5g/>
- Plantin, J.-C. (2021). The geopolitical hijacking of open networking: the case of Open RAN. *European Journal of Communication*, (4)36, -404-417 <https://doi.org/10.48550/arxiv.2202.01032>
- Polese, M., Bonati, L., D'Oro, S., Basagni, S., & Melodia, T. (2022). Understanding O-RAN: architecture, interfaces, algorithms, security, and research challenges. *arXiv (Cornell University)*. <https://doi.org/10.48550/arxiv.2202.01032>
- Rakuten. (2024, Feuary). *Rakuten Symphony and NOW Telecom Sign MoU for 5G Open RAN Pilot in Philippines*. Retrieved from Rakuten Symphony: <https://symphony.rakuten.com/newsroom/rakuten-symphony-and-now-telecom-sign-mou-for-5g-open-ran-pilot-in-philippines>
- Reports Publisher. (2023, February). *Open Ran Market Size Is Projected To Grow From USD 1.1 Billion In 2022 To USD 15.6 Billion By 2027, At A CAGR Of 70.5%*. Retrieved from LinkedIn: <https://www.linkedin.com/pulse/open-ran-market-size-projected-grow-from-usd-11-billion-/>
- Singapore University of Technology and Design. (2023, February). *SUTD to Launch South-East Asia's First O-RAN Open Testing and Integration Centre (OTIC)*. Retrieved from ingapore University of Technology and Design: <https://www.sutd.edu.sg/Research/Research-News/2023/2/south-east-Asia-first-O-RAN-Open-testing-centre>
- Soliman, M. (2022, January). *The Gulf has a 5G conundrum and Open RAN is the key to its tech sovereignty*. Retrieved from Middle East Institution: <https://www.mei.edu/publications/gulf-has-5g-conundrum-and-open-ran-key-its-tech-sovereignty>
- Soliman, M. (2022, January). *The Gulf has a 5G conundrum and Open RAN is the key to its tech sovereignty*. Retrieved from Middle East Institution: <https://www.mei.edu/publications/gulf-has-5g-conundrum-and-open-ran-key-its-tech-sovereignty>
- Telecom Infra Project. (2021, November). *Pandemic and Open RAN in Indonesia*. Retrieved from Telecom Infra Project: <https://tip.telkomuniversity.ac.id/2022/05/19/pandemic-and-open-ran-in-indonesia/>
- Telkom University. (2020, December). *Telkom University and TIP Officially Launched the First Laboratory in Southeast Asia*. Retrieved from Telkom University: <https://telkomuniversity.ac.id/en/telkom-university-and-tip-officially-launched-the-first-laboratory-in-southeast-asia/>
- Text - H.R.6624 - 116th Congress (2019-2020): Utilizing Strategic Allied Telecommunications Act of 2020. (2020, November 18). <https://www.congress.gov/bill/116th-congress/house-bill/6624/text>
- The White House Press Release. (2023, June). *Joint Statement from the United States and India*. Retrieved from U.S. Embassy & Consulates in India: <https://in.usembassy.gov/joint-statement-from-the-united-states-and-india/>
- The White House. (2021, May). *U.S.-ROK Leaders' Joint Statement*. Retrieved from The White House: <https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/21/u-s-rok-leaders-joint-statement/>
- The White House. (2023, August). *The Spirit of Camp David: Joint Statement of Japan, the Republic of Korea, and the United States*. Retrieved from The White House: <https://www.whitehouse.gov/briefing-room/statements-releases/2023/08/18/the-spirit-of-camp-david-joint-statement-of-japan-the-republic-of-korea-and-the-united-states/>

- Tomás, J. P. (2021, November). *Germany announces \$344 million fund for O-RAN projects*. Retrieved from RCR Wireless News: <https://www.rcrwireless.com/20211111/feature/d/germany-announces-344-million-fund-oran-projects>
- U.S. Department of State. (n.d.). *The Clean Network*. Retrieved from <https://2017-2021.state.gov/the-clean-network/#:~:text=The%20Clean%20Network%20program%20is,as%20the%20Chinese%20Communist%20Party>: <https://2017-2021.state.gov/the-clean-network/#:~:text=The%20Clean%20Network%20program%20is,as%20the%20Chinese%20Communist%20Party>
- U.S. Mission Japan. (2022, June). *USAID Launches Asia Open RAN Academy*. Retrieved from U.S. Embassy & Consulates in Japan: <https://jp.usembassy.gov/usa-id-launches-asia-open-ran-academy/>
- Wypiór, D., Klinkowski, M., & Michalski, I. (2022). *Open ran—radio access network evolution, benefits and market trends*. *Applied Sciences*, 408.