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Managing 5G Technology: Using Quality of Experience (QoE) to Identify the Innovation Enhancement Pattern According to the Indonesian Market

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ABSTRACT The coevolution of 5G technological development and the growing market toward the 5G era has generated an innovation enhancement pattern. Identifying this pattern will reveal the 5G services in demand in the market and the infrastructure required for improving the 5G era. Herein, the patterns of 5G technological innovation enhancements are identified as expected in the Indonesian market. We use a novel approach that combines the users' accumulated experience of mobile technology and market expectation. Two types of questionnaires are developed for this purpose: the first determines the quality of experience (QoE) parameters of 4G compared to the preceding 3G and 2G generations and the second analyzes the expectation of QoE parameters for 5G. This study defines 15 QoE parameters reflecting the aspects of infrastructure and services together with their impact on users. The users' answers are classified into six clusters, which are translated into the innovation enhancement pattern. The findings reveal a pattern in which the Indonesian market is predominantly characterized by satisfied users who expect 5G to provide a better experience than 4G, 3G, and 2G despite the presence of some disappointed users in the market who require specialized innovation with variation in disruptive ways. In terms of 5G infrastructure, certain essential patterns include innovation enhancement to serve remote areas, the increasing significance of connectivity to non-cellular and free-service applications, and the market's constant requirement for a better handset while the local industry may harness the opportunity to complete the 5G ecosystem. In terms of service, essential patterns include a strong need for 5G service innovation to render users more innovative, maintaining societal values while delivering the service, and the service innovation required to connect religious life and the 5G service, which should make users feel more healthy and fit. Finally, we discuss how the patterns recognized herein can help mobile operators to develop appropriate strategies for successfully implementing 5G technology.

INDEX TERMS 4G, 5G, Indonesia, innovation, market, quality of experience.

I. INTRODUCTION

In 2018, long term evolution (LTE) release 15 was concluded as the first complete radio network for the 5G mobile technology standard, which promises up to 100 Mbps user experience data rate with an operating spectrum at the sub-6 GHz LTE and millimeter wave band [1]. However, 5G technology is continuously evolving and does not stop when a standard is accepted with the corresponding infrastructure and services released. This technology and its market are coevolving, creating a pattern of innovation enhancement targeted toward the 5G era and beyond.

As the fourth biggest market in the world, Indonesia is an important market for 5G [2]. The 5G service proponents are simply waiting for the best time to commercially launch the technology. With this launch, mobile network operators may become digital service providers that not only deploy the network but also provide relevant service applications. Thus, an important process for such a network deployment is to acquire sufficient information on the market feasibility of the

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deployment. This poses the following question: ''what type of innovation is required to provide appropriate infrastructure and services in the 5G era''? The answer to this question depends on the pattern of innovation enhancement, which is defined as factors that arise from market disorder and uncertainty, which can lead the way to the successful diffusion of a 5G technology in that market.

Herein, we report our work on identifying the pattern of innovation enhancement for 5G infrastructure and service implementation in Indonesia. This study focuses on the mobile users' perspective to determine the nature of innovation enhancement expected by the market. However, to determine such a pattern is a composite effort because mobile technology users behave in a random manner, i.e., they are unpredictable, rendering the market uncertain and complex. Thus, in addition to ordinary market surveys, a new approach to acquire a more convincing answer is required.

Therefore, we developed a new approach by combining the Indonesian market's expectations and measuring their cumulative experiences, using the technological innovation theory of cumulative technological advances [3], [4]. Technically, 5G mobile technology was developed on the basis of cumulative patterns observed during the 1G, 2G, 3G, and 4G eras. By applying the theory in the field of mobile technology, we argue that the innovation patterns of 5G and further generations can be determined using the cumulative experience of the users when they are using the preceding generations to 5G.

Our novel approach is developed according to the primary data acquired by asking 150 mobile subscribers, a random sampling of the Indonesian market, to answer two types of questionnaires in January 2020. The first questionnaire measures the value of quality of experience (QoE) from mobile subscribers who have subscribed to and experienced all mobile technological generations from 2G to 4G. The second questionnaire obtains their expectation of experience value for 5G technology. The users' answers are subsequently classified into six clusters that are analyzed to plot the innovation enhancement pattern. By measuring the QoE, we can determine the ''human factor'' of the users' experience [5], including their psychological perceptions of disappointment and satisfaction. The two questionnaires described above are the core of our novel approach, markedly distinct from an ordinary market survey that only determined market demand without considering the users' accumulated experience and psychological responses. Our primary concept is that 5G innovation enhancement should address user disappointment and increase user experience as well as satisfaction compared with preceding mobile technologies.

This study provides a practical understanding of the Indonesian market. The results of this study will be of interest to 5G proponents investing in infrastructure and services to develop accurate strategies to attain successful technology implementation. This study is a continuous work on our previous research regarding the use of QoE as a diagnostic tool to understand technology profiles [6], [7] as well as a part of consecutive works focusing on Indonesian cases [6]–[8].

This study contributes to the interdisciplinary aspects of 5G mobile communications technology. Our proposed approach was developed by referring to existing theories, i.e. theory of technological innovation, theory of Quality of Experience (QoE), and psychological theory of user satisfaction and disappointment, so that the results of this study would enrich such existing theories. In the frame of technological innovation theory and QoE theory, our study reiterates that the use of QoE can be used as a diagnostic tool to build innovation patterns. Within the framework of the theory of user satisfaction and disappointment, this study has also succeeded in bridging the psychological theory to the 5G technical practical case, in order to obtain more comprehensive results.

The rest of the paper is organized as follows. Section II addresses the Indonesian market profile and the development of theories for the proposed approach; Section III describes the data and results after the proposed approach is implemented; Section IV expounds on the pattern of innovation enhancement and discusses implications; finally, Section V presents conclusions.

II. THEORIES AND METHODS

A. THE INDONESIAN MARKET

Similar to other countries, Indonesia is anticipating commercial 5G deployment. In 2018 and 2019, trial and testing was conducted on the feasibility of the millimeter wave spectrum at 26 and 28 GHz. Apart from these spectrum candidates, Indonesia considers the 3.5 GHz spectrum as it reaches larger geographic areas, providing a more efficient platform to serve urban and suburban areas.

Indonesia has a well-known profile as the country with the largest islands and the world's fourth biggest market, with a population exceeding 250 million. As shown in Figure 1,

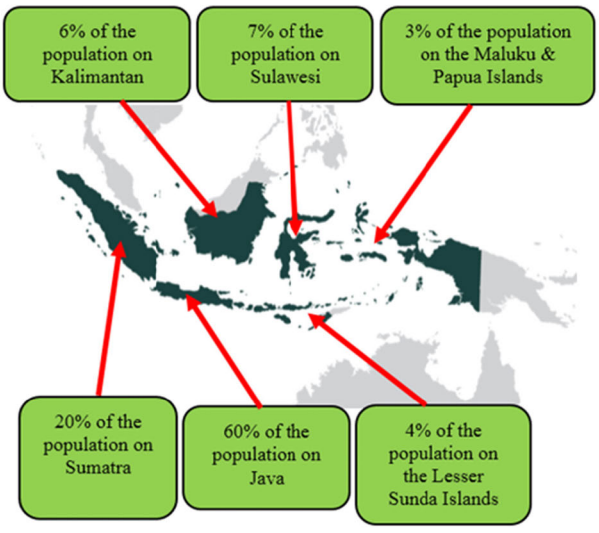

FIGURE 1. Demography of the Indonesian population in the six main island regions of the country [7], [8].

60% of the Indonesian population inhabits the island of Java, with over half the population residing in urban areas; of these urban areas, Jakarta is the most populated area.

Still considered as a developing country, in 2019, Indonesia had a Gini ratio of 0.38, 5.09% economic growth, and a GDP of $1.112 trillion, making it the 16th largest economy for domestic products worldwide. Considering human resource development, we can classify Indonesians as a mid-educated market, involving a mixed social class between traditional and modern. The country is a weak technological producer; hence, mobile subscribers are merely considered consumers.

The technological regime of mobile technology in Indonesia began in 1994 when the country was introduced to the second-generation global system for mobile communications (2G-GSM) technology by a national operator of Telkomsel and Indosat. Together with XL operator, these operators subsequently deployed the nationwide 3G-WCDMA network in 2006 and 4G-LTE Advanced network in 2015. By 2008, Indonesia enjoyed 11 wireless telecommunication operators that used various 2G and 3G technologies; thus, mobile technology was successfully deployed throughout the country. By 2019, only five national operators survived in the current 4G era, serving almost all populated areas, with Telkomsel controlling the largest market share.

B. PROPOSED APPROACH TO BUILD THE INNOVATION ENHANCEMENT PATTERN

1) INNOVATION ENHANCEMENT

Currently, mobile operators are under pressure to immediately roll out 5G services, even though those services require a significant level of investment. However, operators are optimistic that 5G will provide new potential benefits. Thus, operators must be able to successfully manage 5G with financial benefits.

Given that 5G is a technological innovation, operators must understand the pattern of development for such an innovation, either by itself or as developed by the operators, to ensure that the innovation is successfully implemented in the market. This is known as the ''innovation enhancement pattern.'' It is noted that phrase of ''pattern'' is more accurately describes the ''aggregation of factors'' (obtained later from the findings of this study) stemming from market irregularities and uncertainty.

2) BASIS OF THE PROPOSED APPROACH

The innovation pattern can be identified from two perspectives: the perspectives of the market and technology developers. Herein, we utilize the following theory of innovation system: institutional actors may coevolve with technology in a complex process [4]. In the context of mobile technology, the technology developer and implementer (including operators and vendors) have to establish a coevolution mechanism with the market. From the perspective of institutional actors or technology creators (such as mobile operators and technology vendors), innovation should be developed based on recurring adaptation capability to the market [9]. Furthermore, the institutional actor of the market, i.e., the mobile user, may exhibit a technological demand owing to a changing behavior, dynamic expectation, and lifestyle alteration after they adopt the innovation developed by technology creators. The new innovation is created considering such action and response.

Our proposed approach adopts the market perspective, as shown in Figure 2. In practice, the data from the market can be easily obtained through questions about their expectation. However, in our approach, we propose a combination of market expectations and cumulative experiences.

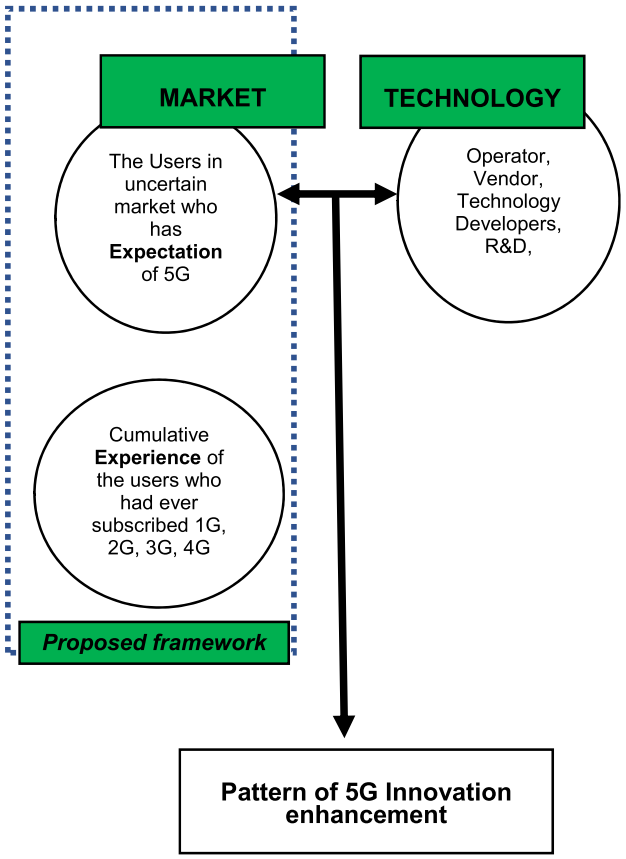

FIGURE 2. Basis of the proposed approach.

This is because the theory of technological development has an important concept that technological advancement is ''cumulative,'' i.e., today's technological advancements proceed from the past, building on what has been previously achieved by improving it in various directions [3], [4]. The supportive assumption is that, 5G mobile technology experienced series of progressive development revealing an increase in innovation from 1G, 2G, 3G, and 4G. However, users have subjectively evaluated the technological innovation in every generation. In the context of mobile technology, such an experiential value is measured using QoE.

TABLE 1. The sequence of technological innovations from 1G to 5G.

	1G	2G	3G	4G	5G
Main technical characteristics	Supporting cellular voice service	Supporting voice and introducing value-added services, such as SMS	Supporting multimedia communication at a data rate of 2 Mbps	Improving 3G performance by introducing a data rate of 100 Mbps on mobility and 1 Gbps on stationary	Supporting three used case scenarios, i.e. - eMBB : to perform 20 Gbps downlink - mMTC : to support 1 million devices per-km-square - uRLLC: to realize 1 ms latency
Official name	-	-	IMT-2000	IMT-Advanced	IMT-2020
Key Technological Innovations	Analog techniques	- Time Division Multiple Access (TDMA) - Digital modulation (e.g. GSM standard used GMSK - Convolutional coding - Speech coding (e.g. Linear Predictive Coding in GSM)	- Utilizing bandwidth up 5 MHz - Multiple access technique: CDMA - Convolutional coding	- MIMO - Larger bandwidth up to 20 MHz - Adaptive Modulation Coding up to 64-QAM - Multiple access technique: OFDM of subcarrier spacing up to 15 kHz - Channel coding: Turbo coding (data), Convolutional coding (control plane)	- Massive MIMO and Beamforming - Millimeter spectrum support bandwidth up to 400 MHz - Modulation: Adaptive Modulation Coding up to 256-QAM - Multiple access technique: CP-OFDM with multiple numerologies of subcarrier spacing up to 240 kHz - Channel coding: LDPC coding (data), Polar coding (control plane)
Leading Standards	AMPS, NMT, TACS	GSM, PDC, CDMAOne	W-CDMA, CDMA-2000, TD-SCDMA, EDGE	LTE-Advanced, IEEE 802.16m	LTE Release 15, LTE Release 16 (on developing)
Prominent service innovation applications	Voice	Voice, Text messaging (SMS) and some other value added services (VASs)	General Purpose Technology: data & Internet platform to offer multiple service creation including multimedia service, video call, and Internet access.	Smart home, smart city, object tracking, industry automation, IoT	Mission critical applications, robotic surgery, self-driving car, industry automation, augmented reality

Further, analytical results of QoE measurement can be regarded as part of the technological innovation diagnostic tools. This follows the theory of technological innovation management, as explained in our previous research [7], which suggests that any innovation should apply a diagnostic tool to define a strategic plan for improvement [10]. We used this concept in our previous work, to prove that QoE analysis can be used to improve the service of Internet of Things (IoT) [7]. Other research works also utilize both quantitative and qualitative values of QoE, which can be translated into relevant strategic action to improve service performance in relation to the perspective of technology adoption, as discussed in [11], [12].

Typically, the mobile subscribers' experience represents the subjective condition of whether a current technology (4G) is better, the same, or worse than its preceding versions (1G, 2G, and 3G). Typically, when users perceive that a current technology is worse than a previous version, they are disappointed. In contrast, when they feel that the current technology is better, they are satisfied. Thus, the idea is that 5G enhancement should address such disappointment while increasing the level of satisfaction relative to the users' experience with previous mobile technology generations.

Therefore, we hypothesize that the combination of 5G market expectation and cumulative user experience of previous mobi le generations (1G/2G, 3G, and 4G) can provide better results that consider the users' psychological responses.

C. RELEVANT THEORIES FOR THE NEW APPROACH

1) THEORY OF TECHNOLOGICAL INNOVATION FROM 1G TO 5G

Continuous change in mobile technological development from 1G to 4G created a series of progressive innovation. Table 1 shows a sequence of key technological innovation across the generations. Beginning with the all-analog platform in 1G, technological change from 1G to 2G led to a fundamental innovation in the digitalization of cellular mobile phones, with voice being the main commodity and text messages (SMS) being the main value added service. The innovation of SMS was adopted by the global market, indicating a prominent and unplanned success story in mobile

services [13]. In the 2G era, GSM was the world's most popular standard being used by more than 70% of global mobile subscribers.

In the transition from 2G to 3G, technological innovation focused on utilizing an increased bandwidth, code division multiple access (CDMA) as the multiple access technique, and the use of convolutional code for error correction, which enabled data communication at a rate of up to 2 Mbps. The ability of 3G to provide data communication classified it as a general purpose technology (GPT) in addition to its ability to generate pervasiveness and increase innovative activities in other technological branches. The conception of service innovation was also significant in enabling multiservice using 3G. Service innovation provides the source of any new technology [14], and it affects the strategic perspective of 3G operators, in which innovation in service is deemed crucial for success. Wideband code division multiple access (WCDMA) is the most popular 3G standard marking continuous evolution from the 2G standard of GSM.

Innovations from 3G to 4G were more focused on increasing data rates by developing technical aspects of multiple-input multiple-output (MIMO) and orthogonal frequency division multiplexing access (OFDMA) as the core in baseband radio. This new technical enhancement includes a larger bandwidth, multiple access mechanism, and a use of turbo coding as the channel coding scheme. It realizes peak data rates of up to 1 Gbps, in which LTE Release 10 is the leading standard for such technical requirements. The introduction of 4G has intensified a massive diffusion of digital service platforms worldwide. It has ushered in the development of advanced services, including smart homes, smart cities, object tracking, industry automation, and the Internet of Things.

Subsequent work has been conducted to develop 5G mobile technology under the umbrella of IMT 2020. 5G is more than a technical enhancement; it is a technological framework with a vision to create new paradigms in connectivity, supporting various digital platforms and service applications for modern life. Unlike preceding generations, 5G does not exclusively focus on increasing speed; it focuses on facilitating massive IoT applications at extremely low latency. It will enable more advanced services, such as mission critical applications, robotic surgery, self-driving cars, industry automation, and augmented reality.

The innovation pattern of 5G during its standard development has been centered around the massive MIMO, millimeter wave spectrum, and energy efficiency [15]. Moreover, the 5G standard will not only introduce new spectrum bands, higher spectral efficiencies, and higher peak throughput but also target new services and business models [16]. There are three used case scenarios of 5G: enhanced mobile broadband (eMBB) with a technical target to implement 20 Gbps downlink, massive machine type communications (mMTC) with a technical requirement to support 1 million devices per-km-square, and ultra-reliable low latency communications (uRLLC) with the target to operate at 1-ms user plane latency [17].

The development of the 5G standard, also called the 5G-new radio (NR), is divided into two phases. Phase 1 is the LTE Release 15 standard, focusing on the deployment of eMBB usage scenario and the initial initiation of uRLLC, and Phase 2 is the LTE Release 16 standard focused on the mMTC usage scenario. Researchers are also working toward continuing the development of LTE Release 17 and beyond, which is expected to further support the Industrial Internet of Things (IIoT), non-public network (NPN), wireless and wireline convergence, and some other future technological paradigms [18].

Table 1 presents the key technological innovations in LTE Release 15. It includes the utilization of the millimeter wave spectrum to obtain bandwidth operation of up to 400 MHz, the use of 256-QAM (quadrature amplitude modulation) under the adaptive modulation coding (AMC) scheme, and the use of cyclic prefix orthogonal frequency division multiplexing access (CP-OFDM) as a multiple access technique with multiple numerologies of subcarrier spacing (up to 240 kHz).

2) THE THEORY QUALITY OF EXPERIENCE (QoE)

When a technology is introduced to the market, users exhibit a subjective value of how they perceive the technology. This subjective perception is represented by the measurement value of QoE. The QoE is defined as the overall acceptance of an application or service as subjectively perceived by users, which can be influenced by expectations and user context [5], [19]. ETSI TR 102 643 defines QoE as a method of measuring performance according to users based on subjective and objective psychological measurement, for the use of product or service in the Information and Communication Technology (ICT) sector [5]. Subjective psychological measurement depends on user opinion, whereas objective psychological measurement is influenced by technical parameters. In the proposed approach, we utilize subjective measurement based on mean opinion score (MOS), which represents the perception of the users under three conditions—worse experience, similar experience, better experience, wherein the experience is relative to that of preceding technological generations. These three conditions indirectly reflect the nature of satisfaction and disappointment experienced by the users.

Reference [5] clearly distinguishes QoE and quality of service (QoS), where QoS is a primary technology-centered approach to quality, whereas QoE is a complementary user-centered approach. There is a ''human factor'' of user experience (UX) that connects the QoS and QoE, as expressed by (1) [20].

$$QoS + UX = QoE \tag{1}$$

Equation (1) shows that the QoE of a technology is constructed by forming its technical aspects (represented by the QoS parameter) and some parameters relating to the

"human factor" (represented by UX). These user parameters, better known as UX, are defined in [21], [22] as factors that refer to the feelings experienced by users when using products, applications, systems, or services that include how accurately users can navigate the product, ease of use, the relevance of the content displayed covering all aspects of user interaction with the product, application, system, or service [21], [22].

Equation (1) shows that QoE measurement is proportional to UX. Further, in this study, we apply the measurement of UX into the generic psychological market value of satisfaction and disappointment.

3) THEORY OF USER SATISFACTION AND DISAPPOINTMENT

As the objective of our study is the perception of user experience, we should refer to the theory of psychology of regret and disappointment [23]. Users utilizing current mobile technology may have a worse experience compared with utilizing a preceding mobile generation. According to the abovementioned psychological theory, such unconfirmed expectations often result in disappointing user experience [23]. This disappointment results in complaints to the service provider, and word-of-mouth publicity regarding the bad experience, but not in switching to another service provider [24]. Hence, the possibility exists that users who feel disappointed about a current technology may still continue using that technology but with an expectation of a better future version.

This particular psychological theory suggests that user disappointment can be avoided by living up to initial user expectations [25]. People may try harder to attain a desired outcome, wherein investing more efforts will generally increase the probability of attaining a desired outcome, and therefore, decrease the probability of user disappointed [23]. Thus, a strategic response is necessary for a 5G mobile service provider to eliminate market disappointment. Adopting this into the field of technology and innovation, it is necessary for the technology provider to invest in a special innovation to eliminate user disappointment.

As regards satisfaction, we refer to the concept of user satisfaction, defined as the favorability of an individual's subjective evaluations of the outcomes and experiences associated with his or her consumption activities [26], [27]. This theory suggests that a user who is satisfied with a product or service is more likely to repeat the purchase and to recommend the consumption experience to other persons, and investing in user satisfaction is a means of creating a sustainable advantage [27]. However, research performed in [28] presents the notion of competitive intensity that can attenuate competitive advantage and influence repurchase behavior over time. It shows that paying attention to user perception is important because competition erodes the perceptions of differential advantage along unsustainable dimensions [28].

Adopting these psychological theories into the field of technology, we discover a need to strengthen the competitiveness of the new 5G technology to ensure its service sustainability. Therefore, innovation must be intensified to maintain the use of any series of technology. Applying this to the mobile technological series, it can be deduced that 5G as a new technology should be more competitive and offer differential advantage than 4G as the current version. Thus, persistently intensifying the innovation will render 5G more competitive.

D. RELEVANT STUDIES OF 5G IN DIFFERENT REGIONS

Studies on 5G technology, in terms of strategy, implementation policies and management aspects have been carried out by several other studies. Study in [29] the case studies of mobile technological innovation system of 3G, 4G, and 5G in China. It concludes that a well-functioned technological innovation system has facilitated technology development and diffusion, and has also promoted the sustainability of the IT industry in China by pushing forward socio-technical transformation [29].

Study in [30] presents the benchmark report of 5G in Japan. In the plan to deploy 5G, Japan relies on the economic strength of cellular network operators, namely NTT-DoCoMo, KDDI and Softbank. The 5G service implementation will focus on the area of automotive and public transport, smart manufacturing and cybersecurity, wireless cloud-based office and healthcare [30].

Study in [31] presents the survey results of the New Zealand mobile market. It has identified a strong consumer interest in and awareness of 5G, while mobile video will be a strong consumer use case for 5G service in New Zealand.

Study in [32] presents the benchmark report of 5G in USA. The country hopes that by 2025 there will be 200 million of 5G subscriber, representing 50% of mobile phone users. The sectors that are believed to be attractive for implementing 5G in USA, are media and entertainment, automotive and public transport, energy and utilities, health and industrial automation.

The main differences between our research and those studies are two things. First, we focus on the Indonesian market, which is very significant to analyze because Indonesia is the fourth largest market in the world (after China, India and USA). Many studies on 5G technology center on developed or industrialized countries, so the study on Indonesia also represents a study on the implementation of 5G in a developing country. Second, this research uses a novel approach, which is developed from several theories (as already presented in Section II B and II C), and does not rely solely on an ordinary market survey.

III. IMPLEMENTING THE NEW APPROACH TO DERIVE FINDINGS FROM THE INDONESIAN MARKET

The following novel approach was used to build an innovation enhancement pattern for 5G infrastructure and service implementation in Indonesia.

A. DEFINING THE QoE PARAMETERS AND ITS RELEVANCE TO INNOVATION ENHANCEMENT

First, we define the QoE parameters and its relevance to 5G innovation enhancement. This concept is derived from (1), which shows the relationship between UX and the technical performance as reflected by QoS. The pre-assumption is that if we can enhance the QoS performance, its user experience must also be automatically increased and vice versa. For example, strategically improving user satisfaction in terms of cellular service coverage can be translated as a technical effort to improve the QoS performance of radio transmitter technology that emits these signals to reach the users. Ultimately, QoS performance should be translated into a certain relevant innovation enhancement. Under the conception of QoE and UX, the above statements refer to the QoE parameter of ''service coverage'' and UX in terms of ''what users feel about the cellular service coverage.''

As can be observed in Table 2, this study uses 15 author-defined QoE parameters, comprising 7 parameters representing the technical quality of infrastructure and 8 parameters representing the service and its impact on the users. Almost all the QoE parameters in Table 2 are parameters generic, rational, and a basic reference for perceptions of mobile cellular users, such as data rate (QoE parameter #3), technical capabilities of the handset (QoE parameter #5), and several other technical parameters. We also list several special parameters such as QoE parameter #4 related to the accessibility of subscribers to services that work on the free non-cellular spectrum, such as WiFi and Bluetooth.

Naturally, there are some criteria that the mobile users are always in need of getting it better, such as the speed of data rate, security and reliability. However, we still need to know the level of expectations by the users about improving the quality of these criteria. This is necessary to transform the results that will be obtained into related strategies by 5G operators.

As shown in Table 2, the ''speed'' criterion has been explicitly represented by QoE parameter #3 (*Data Communications*). Technically, this parameter is correlated with QoS parameter of throughput and stability of data connection. The ''security'' criterion has been represented explicitly by QoE parameter # 7 (*Security and Privacy*). This parameter correlates with user experience regarding how users feel about data security and user privacy when accessing service over mobile cellular technology. However, unlike the other criteria, we implicitly define the criterion for ''reliability'' on the QoE parameter # 1 (*Service coverage in remote areas*). This aims to get a more objective assessment by the user of the technical performance of signal strength and signal availability. Moreover, providing service coverage in remote areas is still a continuous challenge for operators in Indonesia.

B. MEASURING QoE AND USER EXPECTATION

Next, we subject the mobile technology users to a MOS questionnaire. In this study, we utilized a random sampling of 150 respondents in January 2020, while the mode on asking the questions is online survey. To obtain the users' cumulative experience, the main criteria to be a respondent is to be a consistent mobile user who has subscribed to all mobile technologies in Indonesia over time. The 2G era began in 1994 in Indonesia, while the 3G era began in 2006 and the 4G era began in 2015. For this reason, our respondents' ages range between 35 and 55 years old.

The survey has been conducted with the distribution of respondents following the demography of the Indonesian population, which is spread over the six main island regions, as illustrated in Figure 1. The detailed demographic profiles of respondents are presented in Table 3. It shows that some respondents not only subscribe to mobile cellular as the only communication platform, but they also simultaneously use other technologies, such as fiber optic, WiFi and satellite phone.

The respondent was given 2 types of questionnaires: the questionnaire to measure QoE and the questionnaire asking for the mobile user's 5G experience expectation. To measure the QoE, the questionnaire refers to the statement of UX presented in Table 2. MOS is obtained based on the choice of scores 1, 2, and 3. Each score presents a psychological experience value representing the following, respectively: 4G is worse than, similar to, or better than 2G and 3G. It must be noted that we only take into 2G and 3G as the preceding technologies before 4G, since 1G having never been introduced.

To measure user expectation, we asked respondents to simply compare their expectation of 5G with that of the current 4G technology. In our approach, we utilized MOS, which represents the users' expectation value using a scale characterized by the following question ''*do you want the new technology to be worse, the same as, or better than the preceding technology''?* Figure 3 shows the example of the two questionnaires using two parameters from the 15 QoE parameters used herein.

C. MAPPING THE USERS' ANSWERS INTO SIX CLUSTERS OF USER EXPERIENCE

We mapped each answer from the question of measuring QoE and combined them with answers from the question of asking 5G experience expectation. The results can be classified into six clusters of UX, which represent the market segment as well as the users' psychological subjective perception, as detailed in Table 4.

1) ''SAME–SAME'' CLUSTER: CONSERVATIVE USERS WHO FELT THAT 4G HAS BEEN THE SAME AS 3G/2G AND THUS EXPECT 5G TO BE THE SAME

These conservative users are respondents who chose the score combination of (2, 2), that is, answer score = 2 for the ''question of measuring QoE'', and answer score = 2 for the ''question of asking 5G experience expectation.'' They felt

TABLE 2. QoE parameters, User Experience, and QoS translation into the agenda of innovation enhancement.

No.	QOE = UX + QOS			
	QOE PARAMETERS		UX (USER EXPERIENCE DENOTING THE "HUMAN FACTOR" PERCEPTION)	QOS/TECHNICAL PERFORMANCE/RELEVANT INNOVATION AGENDA
1	INFRASTRUCTURE	#1: Service Coverage in remote areas	How users feel about the signal reaching their location in remote areas and special areas that are difficult to reach using mobile signals; e.g., locations at sea, in the middle of the forest, in the desert, and in in deep rural areas.	Signal strength, Signal availability
2		#2: Quality of voice communication	How users feel about the quality of cellular voice connection	Voice clarity, Signal stability
3		#3: Data communication	How users feel about the quality of cellular data communication (Internet)	Data rate (throughput), stability of the data connection
4		#4: Handset feature to access non-cellular platform	How users feel about the features of the handset in terms of accessing non-cellular technology systems, such as WiFi, BlueTooth, etc.	Accessibility to non-cellular platform
5		#5: Technical capabilities of the handset	How users feel about the technical capabilities of the handset	Technical performance of the handset, such as battery (power) consumption
6		#6: Supporting device and accessories	How users feel about the quality of mobile cellular supporting devices and accessories, such as power bank, headset, etc.	Technical performance of supporting devices and accessories
7		#7: Security and privacy	How users feel about security and privacy when accessing services over mobile cellular technology	Data security, user privacy
8	SERVICE AND IMPACT ON USERS	#8: Accessibility to free service	How users feel about the accessibility to free-service applications such as Whatsapp, Youtube, various social media platforms, and other free mobile app services	Free access to service applications
9		#9: Benefit to user health	How users feel about the benefit of mobile service related to health, medicine, and fitness	Smart health and its supporting service
10		#10: Service outside home	User perception regarding how mobile service impacts the users' daily activities outside the home	Smart city and its supporting services
11		#11: Service inside home	User perception regarding how mobile service impacts the users' daily activities inside the home.	Smart home and its supporting services
12		#12: Impact on social values	User perception regarding social impact, considering whether mobile technology affects the users' social life, including values of family, ethics, friendship, and typical norms of society	Technical and non-technical aspects of the social networking service platform
13		#13: Impact on religious values	User perception regarding the influence of mobile cellular on the quality of the users' religious beliefs	Technical and non-technical aspects related to religious service applications
14		#14: Impact on economic value	User perception regarding economic impact, considering whether mobile cellular technology has an impact on the users' financial income such that users feel more prosperous	Technical and non-technical aspects related to trading, economic, and financial services
15		#15: Impact on innovative value	User perception regarding innovative impact, considering whether mobile cellular technology makes users more innovative, richer in ideas, and more competitive	Technical and non-technical aspects related to user innovativeness and knowledge empowerment

4G to be "the same" as previous technologies of 2G and 3G, and they expect that in the future 5G and further technological generations will be the same as 4G.

This cluster translates into a as the market with no willingness to accept the improved 5G technology over 4G. An example of this market segment includes conservative

TABLE 3. Demographic profile of respondents in this research.

Profile		Number of Respondents
Age	< 18	0
	18-34	0
	35-44	122 (81.33 %)
	45-55	28 (18.67 %)
	> 55	0
Gender	Male	97 (64.67 %)
	Female	53 (35.33 %)
Use of other technologies (together with mobile cellular)	User of WiFi	102 (67.11 %)
	User of fiber-to-the-home (FTTH)	63 (41.14 %)
	User of Satellite phone	13 (8.55 %)

TABLE 4. SIX clusters based on the respondents' score choice in the Question of measuring QoE and Question of Asking 5G Experience Expectation.

		QUESTION OF MEASURING QoE		
	CHOICE OF SCORE	(1) **"4G IS WORSE THAN 2G/3G"**	(2) **"4G IS THE SAME AS 2G/3G"**	(3) **"4G IS BETTER THAN 2G/3G"**
QUESTION OF ASKING 5G EXPERIENCE EXPECTATION	(1) **"5G SHOULD BE WORSE THAN 4G"**	ANOMALY	ANOMALY	ANOMALY
	(2) **"5G SHOULD BE THE SAME AS 4G"**	ANOMALY	"SAME–SAME" *conservative users*	"BETTER–SAME" *conservative users*
	(3) **"5G SHOULD BE BETTER THAN 4G"**	"WORSE–BETTER" *disappointed users*	"SAME–BETTER" *plain users*	"BETTER–BETTER" *satisfied users*

Question of measuring QoE

Please express your CURRENT perception (feel) of using 4G cellular mobile technology, by comparing to previous technology (2G and 3G)

Choice of Score:
1 =I felt 4G is worse than 3G and 2G
2 = I felt 4G is the same as 3G and 2G
3 = I felt 4G is better than 3G and 2G

No	*Question*	*Answer choices*		
		1	*2*	*3*
1	QoE Parameter #1: *What do you feel now, about the signal reaching location in remote areas and special areas that are difficult to reach using mobile signals; e.g., locations at sea, in the middle of the forest, in the desert, and in in deep rural areas.*			
12	QoE Parameter #12: *What do you feel now, about social impact, considering whether mobile technology affects your social life, including values of family, ethics, friendship, and typical norms of society*			

Question of asking 5G expectation experience

Please express your EXPECTATION of new mobile technology of 5G and beyond, by comparing to what you CURRENTLY feel (when using the 4G mobile cellular technology services).

Choice of Score:
1 =I expect 5G (and beyond) will be worse than 4G
2 = I expect 5G (and beyond) will be the same as 4G
3 = I expect 5G (and beyond) will be better than 4G

No	*Question*	*Answer choices*		
		1	*2*	*3*
1	QoE Parameter #1: *What do you expect, about the signal reaching location in remote areas and special areas that are difficult to reach using mobile signals; e.g., locations at sea, in the middle of the forest, in the desert, and in in deep rural areas.*			
12	QoE Parameter #12: *What do you expect, about social impact, considering whether mobile technology affects your social life, including values of family, ethics, friendship, and typical norms of society*			

FIGURE 3. Example of the questionnaires used to measure QoE and user expectation.

users who are satisfied with sending messages using SMS since the era of 2G. They keep using SMS despite the option of using more sophisticated texting platforms such as those offered by 4G and 5G.

2) "BETTER–SAME" CLUSTER: CONSERVATIVE USERS WHO FELT 4G IS BETTER THAN 2G/3G, AND EXPECT 5G TO BE THE SAME

This cluster includes respondents who chose the score combination of (3, 2), i.e., who feel that 4G is better than 2G and 3G, but they expect 5G to be the same as 4G. Almost similar to the "same–same" cluster, this cluster reveals that certain users perceived the improvement in 4G over 2G/3G, but they have no demand for the advanced experience of 5G. Owing to their satisfied experience, there is a slight opportunity to welcome new technology.

3) "WORSE–BETTER" CLUSTER: DISAPPOINTED USERS WHO FELT 4G IS WORSE THAN 2G/3G, BUT EXPECT 5G TO BE BETTER

These "disappointed users" are those respondents who chose the combination of (1, 3), stating that 4G is worse than 2G and 3G, and they expect 5G and other future generations

TABLE 5. Percentage of each cluster from the results of indonesian respondents.

		CLUSTERS					
	QOE PARAMETERS	*"SAME–SAME"*	*"BETTER–SAME"*	*"WORSE–BETTER"*	*"SAME–BETTER"*	*"BETTER–BETTER"*	*ANOMALY*
INFRASTRUCTURE	#1: Service Coverage in remote areas	2%	2%	23%	24%	42%	7%
	#2: Quality of voice communication	6%	4%	9%	19%	61%	5%
	#3: Data communication	2%	3%	9%	12%	74%	1%
	#4: Handset feature to access non-cellular platform	6%	3%	6%	18%	66%	3%
	#5: Technical capabilities of the handset	2%	4%	4%	22%	68%	2%
	#6: Supporting device and accessories	4%	7%	5%	13%	70%	2%
	#7: Security and privacy	2%	2%	8%	28%	54%	2%
SERVICE AND IMPACT ON USERS	#8: Accessibility to free service	5%	1%	6%	17%	69%	0%
	#9: Benefit to user health	10%	3%	6%	22%	57%	4%
	#10: Service outside home	9%	3%	6%	10%	71%	2%
	#11: Service inside home	6%	3%	5%	19%	66%	2%
	#12: Impact on social values	6%	2%	23%	20%	42%	6%
	#13: Impact on religious values	5%	3%	10%	29%	48%	3%
	#14: Impact on economic value	4%	2%	4%	20%	66%	1%
	#15: Impact on innovative value	6%	0%	2%	15%	76%	0%
	AVERAGE	*5%*	*3%*	*8%*	*19%*	*62%*	*3%*

to be better. This cluster signifies a type of market segment that have a bad experience of 4G, resulting in psychological disappointment, but still believe in the potential of future 5G technology.

4) "SAME-BETTER" CLUSTER: PLAIN USERS WHO FELT 4G IS THE SAME AS 2G/3G, AND EXPECT 5G TO BE BETTER

These plain users are respondents who chose the combination of (2, 3), stating that they feel 4G to be "the same" as 2G and 3G; however, they expect 5G and further technologies to be better. This market segment is not entirely disappointed with their experience, but does not recognize any significant improvement in 4G over 2G/3G technology.

5) "BETTER–BETTER" CLUSTER: SATISFIED USERS WHO FELT 4G IS BETTER THAN 2G/3G, AND EXPECT 5G TO BE BETTER STILL

These satisfied users are those respondents who chose the combination of (3, 3), implying that according to them 4G is better than 2G and 3G, and they expect 5G and further generations to be better still. They already appear satisfied with 4G service, but demand further improvement in 5G and following generations.

6) ANOMALY CLUSTER: USERS WHO EXPECT 5G WILL BE WORSE

Our default hypothesis is that the market never expects future technology to be worse than the current version. Hence, the response of score = 1 to the question of asking 5G experience expectation by any respondent is deemed an anomaly. This cluster includes users who feel that 4G is better than 2G/3G, but they expect 5G to be worse than 4G. Additionally, if they feel that 4G is worse than 2G/3G, their response is still considered an anomaly if they expect 5G to perform similar to 4G, i.e., worse than 2G/3G. Such a phenomenon is considered a strange, inconsistent response, and can be regarded as a wrong answer. Therefore, any results from this cluster are ignored.

D. CLUSTERING RESULTS

After mapping the respondents answer into six clusters, we obtained the results, as shown in Table 5. We have highlighted the percentage shares (using green and blue) with above average values.

The results were analyzed by considering the percentage of QoE parameters in the six clusters of the Indonesian market. This is a crucial step because an in-depth understanding and a comprehensive analysis to translate the findings into the

pattern of innovation enhancement is necessary. The details are discussed in Section IV.

IV. RESULT ANALYSIS AND INNOVATION ENHANCEMENT PATTERN

A. PATTERN OBTAINED FROM GENERAL FINDINGS

1) MARKET DOMINATED BY SATISFIED USERS WHO EXPECT 5G TO PROVIDE MORE SATISFACTION, BUT SOME DISAPPOINTED USERS REQUIRE SPECIAL ATTENTION

Table 5 shows clear results that the ''better–better'' cluster has the highest percentage for each QoE parameter with an average of 62%. Thus, the majority of the Indonesian market is satisfied with 4G, acknowledging that it is better than preceding generations, and the market expects 5G to be better and provide more satisfaction. The fact that the Indonesian market expects all QoE parameters to be better implies that the future has no single parameter to be enhanced, known as ''killer innovation,'' which may be specifically expected by the 5G market. All aspects of innovation should be continuously developed, resulting in complete innovation in both infrastructure and services.

However, despite all the highest percentages falling into the ''better–better'' cluster, we highlight several QoE parameters in the ''worse–better'' and ''same–better'' cluster'' for having above-average percentages. There are respondents in the Indonesian market who are disappointed, and consider 4G to be the same as 2G/3G in the case of some parameters. This reveals a strategic implication that the 5G innovation enhancement should be focused along these parameters.

2) 5G INNOVATION INTENSIFICATION IS REQUIRED TO FULFIL THE EXPECTATIONS OF SATISFIED USERS

The dominance of the ''better–better'' cluster in the market creates a slight dilemma because such users expect 5G to be better but are already satisfied with 4G, and believe it has fulfilled most of their expectations. Hence, if these users are not provided with better 5G service, they are likely to be disappointed and will not adopt 5G.

To maintain user satisfaction, 5G should be kept intensified in persistent manner. Thus, continuous innovation enhancement is required by intensifying the solid improvement of current technical features that have satisfied users. This is because such an improvement of technical parameters has achieved user satisfaction, proving that QoE provides high value experience.

Why does innovation enhancement need to be intensified for the satisfied users? As discussed in Section II-C-3, we refer to the theory that investing in users' satisfaction is a means of creating a sustainable advantage [27]. However, [28] suggests that product competitiveness is one of the primary determiners of how users decide to re-purchase the product. Thus, translating into our technological case, intensifying innovation is the primary approach to make 5G more competitive than 4G.

3) PLAIN AND DISAPPOINTED USERS NEED SPECIALIZED INNOVATION WITH VARIATION IN DISRUPTIVE WAYS

We have highlighted some QoE parameters having above-average percentage shares in the ''worse–better'' and ''same–better'' clusters. These parameters require special attention because they involve some significant market segments that are disappointed and perceive 4G to be the same as 2G/3G.

Therefore, a specialized, alternative innovation enhancement needs to be deployed in disruptive ways. In this conception, ''specialized innovation'' means to provide alternative 5G technology choices in the hope of providing better technological improvement in accordance with market expectations. Such specialized 5G innovation enhancements will produce many variation of innovation products and services. This is being done to satisfy users who provided low responses or are disappointed with the parameters and features of 4G services. On the other hand, ''disruptive ways'' means to provide innovation which is very much different to existing service available in the market, but should be attractive and affordable to the users. The aim is to impress such disappointed users, eliminate their disappointment, and compensate for their bad experience.

However, there should be also a strategy to educate the market and promote technology to create a firm desire to adopt 5G technology.

Why is it necessary to specialize innovation for this cluster of disappointed users? As discussed in Section II-C-3, we refer to the theory of decision making [23], which states that such disappointment in users should be anticipated by minimizing the probability of getting disappointed; this is done by maximizing investment to attain the desired outcome. Specializing innovation is an approach that requires more effort as technology developers have to incur more cost to create such a specialized branch of innovation. The addition of more variation and alternative technology is a huge investment. Developing innovation in a disruptive manner will create competition among technology developers, and allow users to choose from the various available innovations.

4) THERE ARE NO SIGNIFICANT NUMBER OF CONSERVATIVE USERS WHO ARE APATHETICAL ABOUT THE UPCOMING TECHNOLOGY

Table 5 shows that the ''same–same'' and ''same–better'' clusters average at 5% and 3%, respectively, which is statistically insignificant. Thus, the Indonesian market shows no conservative users being apathetical about the introduction of 5G. The opposite of this fact is that most of the Indonesian market can be categorized into the other clusters that expect the 5G to be better than 4G.

B. INNOVATION ENHANCEMENT PATTERN FOR 5G INFRASTRUCTURE

The following are patterns of 5G enhancement in terms of infrastructure.

1) INNOVATION TO KEEP INCREASING DATA RATE REMAINS THE MAIN DRIVER OF 5G INFRASTRUCTURE

Table 5 shows that the QoE parameter #3, concerning data communication has a 74% average in the ''better–better'' cluster, becoming the second largest share among others. Such an Indonesian market segment includes satisfied users for substantial improvement in data rate (throughput) since the era of 2G, 3G, and 4G, but this market segment still expects 5G to show more improvement. This finding is not largely surprising because mobile technology always aims to increase data speed. Therefore, this finding suggests a pattern in which innovation enhancement performed to increase data rate should be intensified, as data rate remains the main driver of infrastructure development.

Translating this finding into certain technical themes that potentially increase the data rate reveals that millimeter wave can be used as the basis of 5G and further generations [33], [34] in addition to upcoming terahertz communication that enables large bandwidth utilization. Such technical work has shown how ''the increment in data speed'' has been consistently innovated while the finding implies that such an enhancement matches user expectation.

Concerning the current 5G standard of LTE Release 15, the data rate (throughput in Mbps) can be calculated based on (2) [35].

$$\begin{aligned} &\textit{data rate (in Mbps)} \\ &= 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \right. \\ &\left. \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right) \end{aligned} \tag{2}$$

Equation (2) shows that the formulation of 5G data rate is mainly determined by the factors of bandwidth (BW), type of modulation (Qm), and the numerology of carrier spacing (μ) used in the OFDM technique. These main factors are proportional to the increased data rate.

Thus, to achieve a desirable QoE, the 5G deployer must ensure that the 5G technical operations truly match such a formula requirement. For instance, operators should operate at a high spectrum band to provide larger bandwidth (increasing the factor of BW). Accordingly, operators need to deploy massive small cell networks that provide close-range signal coverage. This guarantees a required power level to enable the best modulation type of 256-QAM, which provides the highest data rate performance.

2) SATELLITE AND DRONE AS DISRUPTIVE INNOVATION FOR 5G NETWORK INFRASTRUCTURE TO COVER REMOTE AREAS

There is a mixed quality perception of QoE Parameter# 1 (*service coverage in remote areas, such as at sea, in the middle of the forest, in the desert, and in rural areas*). Despite having a 42% majority of market segment under the ''better–better'' cluster, with respondents who are satisfied, 23% of the respondents exist under the ''worse–better'' cluster who feel disappointed and 24% respondents are part of the ''same–better'' cluster who feel 4G coverage is the same as previous 2G/3G coverage. Apart from these different perceptions, all users expect 5G coverage to be improved in remote areas. The 5G deployer should pay attention to this requirement, because Indonesia is an archipelago with a large contour of remote areas and high mobility of transportation means at sea and river. The movement of user mobility is now not only limited to land communication, in urban, rural, and suburban areas, but the area outside these boundaries must also be covered.

Therefore, there should be a specialized technological innovation to cover remote areas supported by 5G network: instead if only targeting urban and central areas, access should be provided to remote areas. The new network platform can thus be deployed in a disruptive way, i.e., it would be different from an ordinary terrestrial network.

This opens up an opportunity for specific technical features by introducing 5G satellite and unmanned aerial vehicles (UAVs or drones) that can cover large geographical regions [36] including highly remote areas and non-terrestrial areas. Recent research have attempted to make these technologies on the 5G platform, as shown in high throughput satellite (HTS), exploiting the Ka-band or the Q/V band, which enables the use of a wide bandwidth [37]. Research presented in [38] suggests the feasibility of drones to play a role in 5G/beyond 5G network, using innovation themes such as altitude optimization, power optimization, traffic offloading, and interference management. Research in [39] proposed the operation of drone and satellites as possible solutions to ease the integration of the massive IoT network underlying the 5G framework. Such a concept is argued to overcome the limited covered area as it is one of the main challenges of 5G terrestrial infrastructure [39]. The generic concept on how drones and satellites can be utilized to cover large areas is shown in Figure 4.

3) CONNECTIVITY TO NON-CELLULAR AND FREE SERVICE APPLICATIONS IS BECOMING IMPORTANT

Table 5 shows that QoE parameter #4 (*handset feature to access non-cellular platforms*) constitutes 66% of the ''better–better'' cluster. Basically, a handset is used to subscribe to tariff-based service regimes (i.e., a cellular connection provided by a network operator in which subscribers must pay a certain rate to avail service). However, handset users are provided with WiFi and other non-cellular connectivity, including Bluetooth ports. This poses a dilemma for operators because someone has a handset that they subscribe to an operator offering 2G/3G/4G cellular service working on a licensed spectrum. However, the current fact is that users can use the handset to access voice and data services on the non-license spectrum as well, without paying a single penny to the official operator to which the users are subscribed. This issue also correlates with QoE parameter #8 regarding the users' accessibility to free services. By connecting to WiFi internet access, users can avail free voice

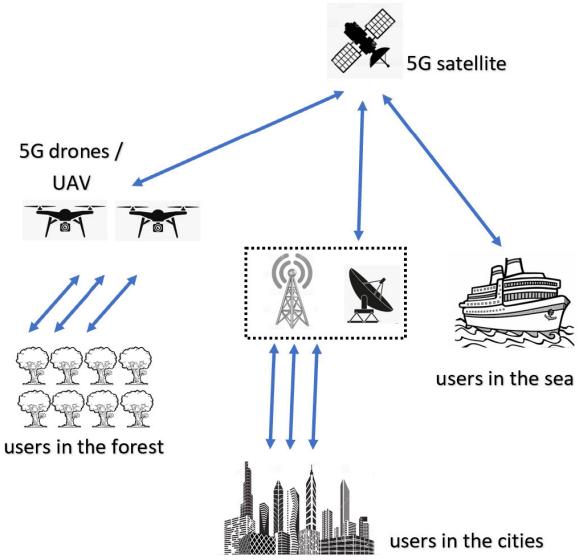

FIGURE 4. Generic concept of satellites and drones covering the areas in cities as well as remote areas.

services through WhatsApp. In fact, the number of Indonesian markets using WhatsApp as an alternative to voice calls is increasing [8], being facilitated by 4G data communication. However, despite competition at the handset level, the integration between license and non-license connectivity, i.e., LTE and WiFi interworking have been proposed as a promising network solution regardless of certain drawbacks [40], [41]. This fact reveals a need to intensify innovation enhancement in the area of handset connectivity to non-cellular and the free-unlicensed spectrum platform.

Practically, the implication to innovation development includes a demand for the 5G handset industry to always support the free-unlicensed spectrum platform. A technical example of the same includes the intensification of WiFi connectivity by innovating on its radio frequency (RF) transceiver to prevent signal degradation, interference, and other technical challenges. Research presented in [42] suggests that innovation on WiFi technologies will compete with cellular technology for hardware resources and design budget. In fact, the capability to support millimeter wave communication is no longer exclusively provided by LTE connectivity. The advancement of WiFi has introduced technology that supports connectivity over the unlicensed 60 GHz supporting 4×4 MIMO downlink [42].

4) THE INDONESIAN MARKET ALWAYS NEEDS A BETTER HANDSET WHILE THE LOCAL INDUSTRY MAY ACCESS THE OPPORTUNITY TO COMPLETE THE 5G ECOSYSTEM

In recent decades, the handset has been transformed to not only provide voice and data communication but also for other varying needs. This began when smartphones replaced the function of certain tertiary devices, such as the camera, game consoles, and TV remotes. Therefore, by considering the findings of QoE Parameter #5 (*technical capabilities of the handset*) it is not surprising that 68% of the Indonesian market feels that the 4G handset performs better than the 2G/3G handset. Interestingly, 22% of the Indonesian market, ''plain users,'' feel that the 4G handset is similar to that of its preceding generations. However, the findings of QoE Parameter #6 (*supporting device and accessories*) shows that 70% of market is already satisfied with the completeness of supporting devices, such as power banks and headsets, but expects the era of 5G to be better.

Combining these facts, it should be strategically noted that the Indonesian market expects innovation in handsets with intensified advancement in supporting devices, such as power banks, headsets, and batteries. This has opened up an opportunity for local industries to fill in the gap in the handset industry.

Another lesson is that 5G should be actively promoted to the market segment that recognized no difference between current technological handset and that of preceding technologies. This segment needs an intense targeted campaign on features related to handset technology and will definitely welcome new innovation in handsets.

Technical challenges as well as the opportunities offered by 5G handsets are illustrated in Figure 5. Innovation in handsets should also be developed in alternate ways, by providing various alternative features to improve its technical capabilities. The technical part is to deal with the critical 5G handset hardware design, including battery design constraints, circuit and system design constraints, antenna and product design, and system design tradeoffs [42]. A specialized innovation in the handset includes a proposal presented in [42] about distributed-phased-array-based MIMO (DPA-MIMO) built on the Beamforming module on the backside of handsets. It enhances high energy efficiency requirement and reduces channel interference when transmitting 5G a data stream.

Another prominent challenge is connectivity with sensors. Technically, 5G used case of mMTC should support a connection density of 1 million IoT per square kilometer [17]. Thus, the 5G handset should contain innovation enhancement to work as a sophisticated sensor and integrate with other external sensors. Together with global positioning system (GPS), the common sensors embedded inside a handset, include the accelerometer, gyroscope, proximity sensors, ambient light, and touchscreen sensors. In contrast, external sensors include humidity, temperature, ultrasonic, and other functional sensors matching with the relevant applications.

5) VOICE QUALITY OVER 5G NETWORK IS IMPORTANT

QoE parameter #2 (*quality of voice communication*) has a majority share in the ''better–better'' cluster showing satisfying improvement. However, it also comprises 19% of the users belonging to the ''same–better'' cluster who feel that the voice and signal stability in 4G has no improvement over 2G/3G. In Indonesia, voice service over 4G network is passed through the circuit switch (CS) fallback mechanism to the GSM platform; consequently, its technical aspect may cause

FIGURE 5. Technical challenges and opportunities for 5G handset.

such a phenomenon. In contrast, the subjective perception of users who feel improvement is supported by the fact that voice-over-Internet is becoming better in 4G. This is in accordance with the previous finding that users are demanding voice connectivity over data platforms such as WhatsApp.

Thus, 5G innovation enhancement should ensure voice clarity over a data network. Although 5G focuses on data, voice communication is expected to be maintained and should even perform better.

An example of innovation specialization is a research on source compression for Indonesian local languages [43], which suggests that Indonesian markets have better compression rates and lower outage probability. The eventual benefit of the innovation eventually leads to better voice experience on 5G services involving language compressions, such as hologram-based telephone services and voice command of self-driving car [43].

6) 5G INNOVATION SHOULD PROVIDE IMPROVE THE USERS' CONFIDENCE IN SECURITY AND PRIVACY

Table 5 shows that in the QoE parameter #7 (*security and privacy*), the second largest share (28%) involves the market segment that perceives their security and privacy under 4G technology to be the same as before. However, security and privacy are important parameters in the 5G era, as suggested by [44]. The 5G network raises serious concerns regarding privacy breaches, when supporting more vertical industries such as m-healthcare and smart transportation. Therefore, security and privacy parameters must be technically guaranteed along with the advanced services supported by the 5G network. New specialized features as a product of innovation alternation and variation must be intensified to increase the users' confidence in security and privacy in the 5G era.

Considering the relevant QoS, the innovation theme is concerned with technical aspects of data confidentiality and end-to-end security, particularly about key generation along with the parameters required for the 5G-IoT technology [45]. The specialized technical feature of relevant innovation themes includes 5G wireless security architecture based on identity management and flexible authentication, as proposed by [44]. An example of applied innovation is the research by [46] proposing speech enhancement for secured voice communication using a technique of coupled Spectral Subtraction and the Wiener Filter.

C. PATTERN OF INNOVATION ENHANCEMENT FOR 5G SERVICE AND IMPACT ON USERS

The following are patterns of 5G enhancement in terms of service and impact on users.

1) A STRONG NEED OF 5G SERVICE INNOVATION TO MAKE USERS MORE INNOVATIVE, RICHER IN IDEAS, AND COMPETITIVE

The highest share of the ''better–better'' cluster (76%) is QoE parameter #15 concerning *the innovative impact, where mobile cellular technology makes users more innovative, richer in ideas, and more competitive*. This dominant value signifies the pattern that the Indonesian market places the highest concern on an eventual mobile technological impact. The Indonesian market is fully aware that any advancement in mobile technology would enable massive information sharing over the Internet and global data communication. This has brought knowledge empowerment, enriched the users' mind, provided more confidence, and enlightened their knowledge.

In response to such market concerns, 5G service innovation which may make users richer in ideas and their knowledge should be enhanced in a persistent manner. Continuous innovation enhancement on improving the technical features of 5G and further generations should be coupled with the aim to create impact values. Thus, majorly infrastructure and service should be built on technology, but they should also focus on creating the desired outcome.

One typical service innovation platform of this parameter is social innovation. The concept of social innovation focuses on the ideas and solutions that create social value as well as the processes through which they are generated, regardless of where they originate [47]. In this concept, exchange of ideas and values has been a strong driver of social innovation. An example of how technology supports the social value is the ease in crowd funding of social donations using Internet access.

2) 5G SERVICE SHOULD LEAD THE USERS TO ECONOMIC BENEFIT

Considering QoE Parameter #14 (*impact on economic value*), 20% of the market falls into the ''plain users'' category,

who feel that 4G brought ''no-change'' in their economic prosperity compared with 2G/3G. It is a common agreement that the diffusion of digital technology is correlated to the general level of socioeconomic development [48]. The penetration of mobile technology with Internet access essentially may increase economic growth and have an impact on better societal life, in terms of prosperity and economic status. Consequently, this Indonesian market segment should be the primary aim of innovation in the era of 5G and future generations, focusing on how any service innovation can bring a positive economic impact.

Thus, any 5G innovation enhancement leading to economic benefit to the users must be intensified. There should be service specialization in alternate ways, promoting various platforms that eventually lead the users to be more financially independent. A clear example of specialized service innovation to bring direct economic benefit is a public trading service and an electronic market place. A specialized service can be structured in a more advanced innovation, such as a financial technology (Fintech) service platform. 5G will enable more secured and reliable low-latency communications, which benefit the process of economic transaction and data sharing among users. The innovation will make financial transactions more instant, secured, and updated in real time. As discussed in [49], the financial services industry already put a higher expectation that 5G will improve real-time mobile trading, and high-frequency trading, while also will reduce risks in the financial sector as 5G provides a more secure transactions.

3) SERVICE INNOVATION UNDERLYING FREE SERVICE APPLICATIONS AND FEATURES ARE IN HIGH DEMAND

Considering QoE parameter #8 (*accessibility to free service*), 69% of the Indonesian market is satisfied with the advancement of 4G to access free services, and expect this to improve in the 5G era. This finding is also in accordance with the finding of QoE parameter #4 that a major portion of Indonesian market wants 5G technical handsets to be better connected to access non-cellular services, which are none other than free and non-license services. The popularity of free telephone services, such as WhatsApp, has made users alter their phone calls from an operator-tariff-based traditional voice calls to the free-call over data communications. People can easily make a WhatsApp voice call, which is free, over any available free WiFi hotspot.

This reveals a pattern that service innovation underlying free service applications should be intensified, as these features are significantly expected by the market. The open-platform is becoming crucial as it facilitates collaborative works to bring any non-licensed service to the market. A persistent way to keep innovating on such technical features is strongly required by the Indonesian market.

The Indonesian market tends not to adopt the concept of a lock-in business, which makes the subscriber depend on 5G operators. For example, once in the 3G era, operators had offered bundling between certain brand services and handsets with a certain time contract duration. However, the Indonesian market is more satisfied if they have a free choice of handsets available on the market. This will also apply in the 5G era, where free choices are more widespread in terms of ecosystems, not only handsets, but other devices and services such as IoT, cloud platforms, and smart home service.

4) 5G SERVICE INNOVATION SHOULD NOT BE AGAINST THE VALUE IN SOCIETY

The QoE parameter # 12 (*the social impact, where mobile technology affect social life, including values of family, ethics, friendship, and norms in society*) includes divided perceptions. There are 23% disappointed users who consider 4G technology to make things worse (''worse–better'' cluster), whereas 20% consider it makes no difference as preceding generations (''same–better'' cluster). It is interesting to see that the difference among those cluster with ''better–better'' cluster are not that significant, whereas satisfied users are 42%. Nevertheless, the whole group hopes that the presence of 5G technology will positively impact social values.

This phenomenon is not too surprising because most Indonesian people are still classified as traditional and religious who uphold family values and ethics in society. There are several incidents of crime, fraud, and family breakdown caused by shifting norms and values due to the negative impact of technology. For this reason, we indicate the pattern of innovation enhancement that any intensification of service innovation should be developed in line with societal norms. There is even market opportunity to adopt services which may strengthen ethical values in society.

5) THERE IS A NEED OF 5G SERVICE INNOVATION RELATED TO RELIGIOUS BELIEFS

QoE parameter #13 concerns *the influence of mobile service on the quality of users' religious belief*. The share of ''worse–better'' cluster signifies that 23% of Indonesian market consider 4G to have worsened their experience. Nevertheless, an aggregated 87% users hope that the contribution of 5G technology to religious belief will be better.

We should highlight the 23% users who are disappointed. This implies a user perception that 4G technology makes people complain about their religious life. It can also be due to their perception of world conditions, wherein it is deemed that modern people neglect religious activities because they are busy in enjoying the easy atmosphere brought by 4G technology.

Thus, a pattern emerges wherein there is a need for the specialized service that can have a special impact on religious life in the 5G era. The majority of Indonesia's population is practical Muslim who are very concerned about their religious life. Technology developers should consider introducing new features by formulating relevant service innovation, which will not only facilitate religious ritual worship but also other relevant aspect. For example, service applications which support the Islamic financial technology [50].

6) ANY 5G SERVICE INNOVATION, NOT ALWAYS HEALTH-RELATED SERVICES, SHOULD MAKE USERS HEALTHIER AND MORE FIT

We note QoE parameter #9 (*the benefit of mobile service related to health, medicine and fitness*), which has an interesting result: 22% of the Indonesian market feel that the advancement of 4G did not come have a good impact on user health and fitness. Thus, any 5G innovation should be intensified to make users feel healthier and fit. However, such an innovation can be no longer limited to the mobile health service; various services should have been specialized to offer an indirect benefit for the users' health.

An example of specializing non-related health services are applications that facilitate volunteering activity and social experience. A recent study suggests that volunteering may be good for the body and mind as it reduces stress and increases physical activity among people [51]. Such web and service applications are GiveGab and One Today web [52]. These applications utilize a purely technical, non-medical-related advanced technological platform, such as the crowdsourcing mechanism and a technical feature to be more efficient with users posting pictures and their news feed.

7) 5G SERVICE SHOULD EVENTUALLY STRUCTURE THE ECOSYSTEM OF SMART HOME AND SMART CITY

We analyze the QoE parameter #10 and #11 revealing user perception regarding *how mobile technology impact on users' daily activities outside and inside the home*. Table 5 indicates the third largest value of the ''better–better'' cluster (71%) reflects that the Indonesian market realized that 4G has improved aspects of ''outside home activities'' and thus increased user satisfaction. In fact, the essence of supporting ''outside home activities,'' is none other than the eventual benefit of a smart city ecosystem.

This finding signifies a pattern that 5G innovation enhancement must ultimately work towards creating a smart city. This includes not only the physical technical infrastructure but also its regulation, policy aspects, campaigning, and other related features. Thus, the innovation work should be developed under the ''ecosystem paradigm.''

However, the QoE parameter #11 (*service inside home*) indicates that 19% of the Indonesian market perceives no difference in 4G in terms of supporting their ''inside home activities'' relative to 3G and 2G. The essence of technological supporting ''inside home'' activities, is none other than innovation to support the creation of smart homes. In fact, the benefit of mobile technology on creating ''smart home'' is not clearly perceived by some portion of Indonesian market. Therefore, 5G innovation enhancement on creating the smart home should be specialized and promoted to be effectively perceived by the users.

We noted the strong relationship between smart home and smart city. Some crucial innovation of Smart home theme, such as artificial intelligence, cognitive radio, and cloud-of things, are shaping the infrastructure of the smart home network [53], which has also been finally integrated into creating a smart city using 5G infrastructure. Smart home innovation focuses on ''inside home'' technical challenges, such as dealing with interferences and wall penetration loss, whereas the smart city network deals with collecting big data from the home network [53].

The relevant IoT technology is a clear technical example of innovation enhancement to create a smart city. One of the 5G usage scenarios is to sustain mMTC that enables a large IoT network. Pervasiveness and always having a connected network are important for creating a smart city [54]. The work on innovation enhancement has been indicated by the development progress of LTE Release 16 to enable full support for IIoT for Industry 4.0 under the used case of mMTC.

D. TRANSFORMING THE PATTERN INTO APPROPRIATE STRATEGIES

We argue that the pattern that has been obtained will help operators in developing an appropriate 5G implementation strategy. The logical explanation can be connected between the nature of 5G which brings a new paradigm to the digital connected society, and the logical consequences for network operators. The ITU-R M. 2083 document [55] as the main reference explaining the 5G vision (IMT-2020), has stated that the co-evolution between socio-technical trends and the development of mobile technology is becoming stronger, and becomes the foundation of society in 2020 and beyond. It has been a motivation for the direction of 5G technology development, namely providing wireless infrastructure to connect the world, promoting the economy of new ICT market, bridging digital divide, enabling new ways of communications, providing new form of education, promoting energy efficiency, being key driver of social change, and supporting new art and culture [55]. Such a direction for the development of 5G was eventually realized in the used-case scenario that we know today, namely eMBB, uRLLC, and mMTC.

Based on the above conception, the 5G strategic implementation must be oriented to service aspects that co-evolve with socio-technical changes in society, while infrastructure acts as an enabler for the realization of these services. This is far different from the vision of 4G which is centered only on the capabilities of its technical infrastructure aspects. ITU-R M.1645 [56] as the main reference explaining the vision of 4G (IMT-Advanced), states the technical orientation of 4G, which is only an increase in the ability of wireless access to support data speeds.

Thus, the concept in 5G is far different from the previous generation, so that it requires various adaptations to technical and non-technical aspects by network operators. As stated by [57] the logical consequence of the arrival of 5G is that operators need new strategy as well as business model innovation. One possible option for operators is to transform from a ''connectivity provider'' to be a ''digital service provider'' [57].

To help develop the strategy, operators must recognize the possible patterns that will emerge from the

5G implementation plan, and the results of this study will certainly help them in the 5G era. For example, the pattern obtained in Sub-section IVB-1 indicates that increasing the data rate remains a main driver in the infrastructure aspect. By knowing this pattern, operators can choose a strategy to prioritize the development of small cell networks that provide close-range signal coverage, thereby ensuring the availability of high data rates for 5G users. Another example is the pattern obtained in Sub-section IVC-4, indicating that 5G service innovation should not be against the value in society. Knowing this pattern is essential, especially for network operators who wish to transform into digital service providers in the 5G era. This pattern provides an understanding for operators, that the services to be offered to the Indonesian people must be strictly maintained in order to be accepted by the Indonesian market. Operators cannot necessarily adopt services from other countries, but must be customized to suit the values and culture of the community. Furthermore, other innovation enhancement patterns which have been obtained from this study, should be transformed into appropriate strategies for the operator.

V. CONCLUSION AND LIMITATIONS OF THE STUDY

This study presents our work on identifying the innovation enhancement pattern for 5G infrastructure and service implementation in Indonesia. The results have answered the question of ''what innovation should be enhanced to introduce appropriate infrastructure and services'' in the Indonesian market in the 5G era. This study provides a practical understanding of the Indonesian market and aids 5G deployers investing in infrastructure and services to develop appropriate strategies to attain successful technology implementation in Indonesia. This study focuses on the mobile users' perspective, attempting to extract the type of innovation enhancements expected by the market.

We used a novel approach based on combining the users' accumulated experience of mobile technology and market expectation. A basic concept is that the accumulated users' experience of current (4G) and preceding mobile technology (2G/3G) may provide sufficient information on what innovation should be enhanced to better satisfy the users in future technological experiences (5G). The primary data was obtained from 150 mobile subscribers that represent a random sampling of the Indonesian market, who have used all generations from 2G to 4G. They were given two types of questionnaires: the first was to measure the QoE parameters of 4G, compared to preceding generations of 2G and 3G, and the second was to state the expected 5G quality. We defined 15 QoE parameters reflecting the aspects of infrastructure and of services as well as their impact on users. The answers were then classified into six clusters of the Indonesian market, which were translated into the pattern of 5G innovation enhancement. By measuring QoE, we could determine an understanding of the users' psychological subjective perception, including disappointment as well as satisfactions. Our primary concept is that 5G innovation enhancement should compensate for previous psychological disappointments and improve user satisfaction compared with preceding mobile generations.

The results are built into the pattern of 5G innovation enhancement as follows.

A. GENERAL PATTERN

1) The Indonesian market is predominantly characterized by users satisfied with 4G, who expect 5G to provide further satisfaction; however, there are some disappointed users that need to be focused on.
2) 5G Innovation intensification is required to fulfil the expectations of satisfied users.
3) ''Plain users'' and ''disappointed users'' require specialized 5G innovation with variation in disruptive ways.
4) There are no significant number of conservative users who are apathetical about the upcoming 5G technology.

B. PATTERN FOR IMPROVING 5G INFRASTRUCTURE

1) Innovation is required to further increase the data rate.
2) Satellite and drone as disruptive innovation of 5G network infrastructure should be used to cover remote areas.
3) Connectivity to non-cellular and free service applications is becoming even more important in the 5G era.
4) The Indonesian market always needs better handsets while the local industry may access the opportunity to complete the 5G ecosystem.
5) Voice quality over 5G network is important.
6) Innovation should increase the users' confidence in the security and privacy provided in 5G.

C. PATTERN TO IMPROVE 5G SERVICES

1) A strong need of 5G service innovation to make users more innovative, richer in ideas, and competitive.
2) 5G service should lead the users to economic benefit.
3) Service innovation underlying free service applications and features are highly demanding.
4) 5G service innovation should not contradict social values.
5) There is a need of 5G service innovation in accordance with religious beliefs.
6) Any 5G service innovation, not always health-related services, should make users feel healthier and more fit.
7) 5G Service should eventually structure the ecosystem of Smart Homes and Smart Cities.

Finally, this study has a limitation in the sense that the results are subject to the 15 predefined QoE parameters. A further study is recommended to expand the QoE parameters to be more comprehensive and cover more issues in the market.

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