Key Wearable Device Technologies Parameters for Innovative Healthcare Delivery in B5G Network: A Review

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ABSTRACT The future of healthcare relies heavily on the connection of humans to intelligent devices via communication networks for rapid medical response. Hence, the evaluation of the performance of smart wearable devices as veritable tools for prompt, pervasive, and proactive healthcare delivery to end-users in response to socio-economic dynamics is imperative especially as 5G unwinds and B5G emerges. Despite the boom in the wearable market and significant improvement in communication technologies, the translation of wearable data from clinical trials to valuable assets for practical medical application is burdened with varying challenges. This review provides an introspective analysis of the performance of unobtrusive wearable devices based on identified key performance indicators (KPIs) in relation to evolving generation networks in achieving innovative health care delivery. A total of 2751 articles pooled from 5 digital libraries were screened and 16 were selected for this review using PRISMA. The identified wearable KPIs; energy-efficiency, discretization, intelligence, secured network, and customizable standards are currently engrossed with both reliability and real-time issues that undermines its performance, perceptibility, and acceptability by end-users. The transformation of smart wearable device data from clinical trials into intangible resource for medical application is the fulcrum of innovative healthcare actualization. Further insight on how the identified challenges can be streamlined for smooth device alignment and transition to the emerging B5G network and its eco-friendly environment is also discussed. It is hoped that this will serve as a rallying point for research direction in translating prospective wearable solutions into valuable resource for actualizing p-health.

INDEX TERMS Artificial Intelligence, B5G Network, Healthcare, Wearable, Sensing, 5G Network.

I. INTRODUCTION Improvement in wearable device technologies is anticipated as 5G unwinds of and B5G otherwise known as sixth generation (6G) network emerges with emphasis on throughput, improved capacity (speed), network densification, reduced latency (security), and safety-consciousness [1]. This is to ensure that future pervasive healthcare system (hereinafter referred to as “p-health”) is proactive, precise, patient-centered, preventive, participatory, predictive, pervasive, preemptive, and personalized, to meet the global dynamics in disruptive technologies’ demands and delivery [2]. Innovative healthcare delivery is an emerging interdisciplinary area that cuts across the acquisition, processing, transmission, storage, retrieval, and use of health and biomedical information [3]. Wearable technologies, communications, and applications are at the heart of p-health actualization otherwise called connected health (CH) [4]. Wearable applications include wire-
less health monitoring through physical activities, predictive health, assisted living, etc. Sensing and imaging technologies are the two main technologies deployed in p-health.

Due to recent advancement in sensing, networking, and data fusion, the features of unobtrusive wearable devices have undergone tremendous transformation in their usage [5, 6, 7]. First, the provision of real-time health related information through wireless networks has facilitated real-time attention to acute scenarios (such as cardiac arrest, epilepsy, stroke) especially in rural settings and suburbs where expert services were previously inaccessible is now made possible through the availability of 5G network [8] as these devices transmits data over 5G network [9, 10, 11, 12]. Also, unobtrusive wearable monitoring provides precise information for evaluating healthiness and fitness of a person at any instance. Data can be transmitted through mobile phone or on flexible displays allowing for closer monitoring of the users. This has resulted in the promotion of an active and healthy lifestyle. In addition, it helps to detect any potential health risk and facilitate the implementation of preventive measures at an earlier stage. Furthermore, with the global outbreak of Corona virus (COVID-19), the demand for contactless medical delivery surged sporadically to reduce the spread of the virus [13, 14] through physical contact.

However, as 5G unwinds and 6G emerges, there is the need to review introspectively through empirical evidence the performance of the existing wearable devices based on their technological parameters otherwise known as key performance indicators (KPI) to ascertain the level of innovativeness of these devices in response to the envisaged characterization of B5G to guarantee seamless operations for innovative p-health care.

Previous reviews in this area only covered fundamental issues on wearable device designs and sensors without a didactic connection to its technological parameters as it relates to B5G network. Authors [15] and [16] provided in-depth insight into the various materials used in constructing wearable healthcare systems, and identified improvement in its unique properties (such as self-healability, stretchability, biodegrability, etc.) needed for integration in B5G networks. Also, the works of [17, 18, 19] focused on wearable sensors with emphasis on the different autonomous flexible sensors approaches in wearable designs and its characteristics. These works however, did not take into perspective the KPIs and its impact of B5G on its transformations. Authors [20] presented a detailed review on fog computing in healthcare. This work however, focused only fog computing tasks without adequate discussion of the determinants affecting the overall performance of these devices in healthcare delivery. Recently, Aleksandr, et al. [7] presented a state-of-the-art review of the historical background of the wearable device market with a shallow discussion of its underlying communication technologies. Similarly, in a survey carried out by Apeksha et al. [21], their work focused on determining to what extent wearable technologies with integrated artificial intelligence (AI) solutions has helped in predicting user’s health status and its consequence. Furthermore, authors [22] reviewed the different techniques for tracking and recording various human body movements using wearable technology to ascertain quality of service (QoS) of these devices. Though authors [3] carried out a review of key parameters of unobtrusive sensing and wearable devices for health informatics in 2014, their work however demands an upward empirical review considering the dramatic technological transformations witnessed globally in recent times due to upsurge in disruptive technologies and breakthroughs in science and technology.

Despite the significant progresses achieved in developing p-health systems as highlighted by previous reviews, issues such as user acceptance, user-inclusiveness, distributed interference in wireless networks, safety, on-node processing, data privacy, reduction of motion artifact, low power design, etc., need to be addressed to enhance the usability of these devices (especially unobtrusive wearables) in B5G. These reviews had only concentrated on identifying these problems without specifically outlining how the identified issues are linked with their core performance parameters as well as provide sound technical insights on how B5G networks can address these underlying technological bottlenecks.

Is B5G the answer to curbing the identified problems and transiting from clinical trials to data usability from wearable device for practical purposes? How has wearable designs responded to 5G networks? Undoubtedly, the ubiquitous and futuristic use of wearable devices for p-health is invariably dependent on issues associated with its core performance parameters. Therefore, an upward constructive review of these KPIs is imperative to ascertain the extent 5G network has impacted on the advancement of unobtrusive wearable devices and the set the path for 6G integration in actualizing innovative healthcare delivery. Hence, this review is timely given the fact that the window period for the unwinding of 5G is in sight and the emergence of 6G (otherwise known as B5G) unarguably promises greater expectations.

On this premise, this review critically examines unobtrusive wearable devices deployed in health care delivery to ascertain the extent at which its developmental strides matches up with improved speed, security, smartness, and safety concerns of B5G network. The main goal of this review is.

- To examine perspectives and trends in unobtrusive sensing wearable device and designs with emphasis on emerging technological dimensions based on network evolution and socio-economic dynamics.
- To identify key technological performance indicators (KPIs) and drivers of unobtrusive wearable device in response to advancement in communication network and highlight associated challenges.
- To provide an evidence-based technological approach for assessing the performance of wearable devices in a B5G environment.
- To provide an in-depth analysis of the convergence of B5G network characterization, wearable device, and p-
health, and outline possible research directions in addressing identified concerns.

The rest of this paper is arranged as follows: Section II presents the systematic review methodology adopted in this study. Section III discusses socio-economic dynamics propelling the advancement of wearable device technologies. In Section IV, unobtrusive wearable device designs and technologies are explored highlighting the impact of technology on transformative wearable designs. Section V presents the performance parameters and KPIs of wearable devices and discussed associated issues and challenges. While Section VI explored the link between wearable device KPIs and unique characterization of emerging B5G networks, Section VII provides hints on the potentials of B5G KPI to support wearable device technology for advancement of p-health. Section VIII concludes the paper with promising directions for future research.

II. METHODOLOGY

In this study, the preferred and meta-analysis (PRISMA) systematic review methodology is adopted [23]. In all, five databases were adequately searched including IEEE Xplore, MDPI, SpringerLink, PubMed, and Scopus digital library. The search was carried out on each of the database using keywords “wearable device” and “health care” or “wearable technologies” and “5G health care service”, or “unobtrusive wearable” and “5G technologies”, or “innovative health care” and “5G wearable technologies”. The choice of these keywords is for exhaustive search to reflect the PICOS approach (participants, interventions, comparators, outcomes, and study design/limitations) thereby providing enough information about the study scope. In addition, the search is limited to 2014 to 2022.

A. CRITERIA FOR ARTICLES SELECTION AND EXCLUSION

First, authors performed a preliminary screening of all searched articles. Articles with duplicate titles and content were excluded after the glancing through the titles and abstract. Thereafter, authors evaluated the full article content and check its eligibility. The inclusion criteria for an article to be reviewed based on eligibility include:

- That the article is published in a reputable journal or in conference proceedings.
- That the publication year of the article spans between 2014-2022.
- That wearable device technologies and parameters for innovative health care was the primary subject matter for the article.
- That the article content is targeted towards both wearable device growth and next generation communication network.
- That the article is written and published in English language.

All articles that were considered not original research (such as comments, letters to editors) and that did not meet the above criteria were forthwith rejected and excluded from the list of reviewed papers.

B. ARTICLE SEARCH RESULT

In the first instance, 2751 articles were identified from the selected digital libraries. 1201 articles were considered eligible for screening after excluding 1550 duplicated articles. After initial screening, 1021 articles that did not meet the inclusion criteria based on initial screening were excluded. Thereafter, 180 included articles were subjected to full-text article eligibility assessment by two authors. Having excluded 164 irrelevant studies, 16 articles were used for the final review. Fig. 1 depicts the study selection process while Table 1 summarizes the description of articles included in the final analysis and selection for review in this work.

III. SOCIO-ECONOMIC DYNAMICS TRIGGERING WEARABLE DEVICE TECHNOLOGIES ADVANCEMENT

Wearable technologies are electronic devices or computers that are incorporated into clothing or other accessories and worn comfortably on the body. It consists of two different components; wearable and body sensors [27]. Major application areas of wearable technologies include health and medical, fitness and wellness, infortainment, industrial, and military. In healthcare, wearable devices are used to monitor vital signs, and for augmenting senses. Though medical wearable device that are used for monitoring of physical and physiological vital sign has proven to be reliable, yet most people are hesitant to attach physiological sensors to their body largely due to safety concerns and discomforts [3].
| Study | Methodology/Participants | Study Aim | Findings/Outcomes |
|-------|--------------------------|-----------|-------------------|
| Zheng et al. | Evolution of unobtrusive wearable designs | Explored the design strategies for emerging features of unobtrusive integration of wearables in response to advancement in technology | Flexible sensors for wearable features design in medical platforms. |
| Mardono et al. | Wearable technologies and sensor advancements | Advancement of wearable sensor technology improved safety and efficiency of mining operations | Mining and industrial safety and productivity. |
| Wu et al. | Wearable sensors and applicability | To review the utility of wearable sensors in medical and industrial sectors | Wearable sensors in medical and industrial instrumentation. |
| Seshadri et al. | Wearable technology in healthcare | To review the clinical utility of wearable technology | Wearable technology in healthcare. |
| Kraemer et al. | Fog computing task and network level in pervasive healthcare | Data aggregation and network transmission issues in wireless networks | Smart wearable technology. |
| Aleksandr et al. | Wearable market and technology timelines and trends | Wearable technology is in infancy | Wearable technology is encumbered with essential building blocks. |
| Apeksha et al. | Smart wearable technology | To determine the extent of real-time health record. | Wearable technology can create value. |
| Zheng et al. | Emerging unobtrusive and wearable technologies for health informatics | Though significant progress has been recorded, most wearable designs are prototypes in early stages with concerns. | Wearable technology is encumbered with essential building blocks. |
| Sun et al. | Wearable communications and information technology | Highlighted critical issues such as energy, latency, spectrum, etc. | Wearable technology is encumbered with essential building blocks. |
| Kazim et al. | Wearable communications and 5G network for future healthcare | Wearable technology is encumbered with essential building blocks. | Wearable technology is encumbered with essential building blocks. |
| Lin et al. | Wearable sensing, information, and communication technologies for wearable devices | Difficulty in achieving user-friendly designs and technical issues | Wearable technology is encumbered with essential building blocks. |
| Loncar et al. | Wearable devices and data management | Wearable technology is encumbered with essential building blocks. | Wearable technology is encumbered with essential building blocks. |
| Dimauro et al. | Bioelectronic and AI- wearable technologies | AI improved the smartness of wearable technology | Wearable technology is encumbered with essential building blocks. |
| Sharifi et al. | Wearable technologies for medical diagnosis and treatment | Wearable technology is encumbered with essential building blocks. | Wearable technology is encumbered with essential building blocks. |
| Mechanick et al. | Wearable technologies in lifestyle medicine and biomedical concepts | Wearable technology is encumbered with essential building blocks. | Wearable technology is encumbered with essential building blocks. |
| Said et al. | Wearable technology in biomedical and medicine usable resource for practical applications | Wearable technology is encumbered with essential building blocks. | Wearable technology is encumbered with essential building blocks. |
Despite the evolution of generation network (2G-B5G), there is still a shortfall in the expansion and marketability of wearable devices for healthcare purposes partly due to primitive approach in semiconductor production [15]. However, with breakthroughs in material science and innovative technologies, wearable technologies has significantly improved resulting in better wearable designs [6]. In recent time, there has been an astronomical growth of wearable device and its associate technologies [28, 29]. Fig. 2 and Fig. 3 respectively shows the increase in the number of connected wearable devices from 325 million in 2016 to 722 million in 2019 indicating more than double increase within the space of three years. This number is forecast to reach more than one billion by 2022 [28].

![FIGURE 2. Global connected devices 2016 to 2022 in millions](image)

![FIGURE 3. Number of connected wearable device in the United States of America](image)

However, with the outbreak of COVID-19 globally, industrial production process was disrupted across the globe, with the wearable device market inadvertently affected in the first half of 2020 as production units were shut down due to governments imposed restrictions [30]. Notwithstanding, the pandemic also fostered the role of wearable technologies and devices in the healthcare sector with a surge in the demand for contactless healthcare delivery to cushion virus spread [30]. As a result, some players in the wearable technology industry that had developed innovative systems for virus infection detection and possible curtailment [31] witnessed unprecedented patronage as shown in Table 2.

The projected global market demand for wearable device technologies in medical applications was set to be about 17% higher in 2019. Besides, the smart-eye technology was expected to be 40% more in sales than now [31]. In 2019, increase in demand by millennial consumers led to computer electronics application making a whooping 45% contribution to the market share index (see Fig. 4). This gave rise to the development of devices that can maintain luxury standards and meets users’ demands by utilizing the advantage of high-end machine-to-machine seamless communications and connections occasioned by 5G network. With the expected advancement in 5G and B5G network, the global wearable technology market size valued at USD 32.63 billion in 2019 is projected to expand by 15.9% using compound annual growth rate (CAGR) [30].

![FIGURE 4. Global wearable technology market share (Grand View Research, 2020)](image)

As at 2019, the dominant key players of wearable technology market globally are Alphabet, Apple Inc, Fitbit Inc., Garmin Ltd., Huawei Device Co., HTC Corporation, Samsung, Sony Corporation, Xiaomi Global Community [31] as shown in Table 3, with each player having its market share index and segment. These market players continuously undertake strategic initiatives such as new product/service launch, outsourcing of certain processes and functions, mutual contracts and agreements, and merger and collaborations, etc., to sustain their market position, maintain global relevance, and maximize profits. These initiatives are geared towards meeting the demands of millennial end-users [30]. Also, the advancement in network infrastructures, use of sophisticated sensors, AI abilities, and big-data velocity contributed to the upsurge of wearable devices, with the desire to improve the safety, productivity, and decision making capacity of these device to accommodate futuristic demands and scenarios [32].

Though Fitbit Sense fitness watch, band, and other similar smart watches are not really intended for medical diagnosis and cannot be classified arbitrarily as medical devices, yet

### Table 2. Forecast for Wearable Devices Worldwide [31]

| Wearable Devices | Period under Review |
|------------------|---------------------|
|                  | 2016 | 2017 | 2018 | 2021 |
| Smart watch      | 34.80| 41.50| 48.20| 80.96|
| Wristband        | 34.97| 44.10| 48.84| 63.86|
| Sports watch     | 21.23| 21.65| 21.65| 22.31|
| Bluetooth headset| 128.50| 150.00| 168.00| 206.00|
TABLE 3. Major Players in Wearable Device for Healthcare

| Devices     | Target Area | Major Market Players                               |
|-------------|-------------|---------------------------------------------------|
| Hearable    | Tech        | Apple, Bose, Google, Huawei, Samsung, Sony         |
|             | Healthcare  | Jabra, LifeBeam, Nuheara, Vinci                   |
| Smart watches | Tech    | Apple, FitBit, Garmin, Sony, Samsung, Xiaomi      |
|             | Healthcare  | Alivecare, Empatica, KinesisU, Nemaura, Omron, OnePulse, PKvitality, Verily |
| Fitness Trackers | Tech | Samsung, FitBit, Garmin, Nike, Xiaomi            |
|             | Healthcare  | iHealth, Alivecare, BrainSentinel, Misfit, SpireHealth |
| Eye Wear    | Tech        | Google, Samsung, Microsoft                       |
|             | Healthcare  | Vusix, Epson, Virtamed, eSight, OssoVR, Immersive solutions, Medical Realities, VirZOOM |
| Body Device | Tech        | Google, Athens, Sensoria, OM Signal              |
|             | Healthcare  | Siren, Bonbouton, NeuroMtric, Hexoskin, Sensoria, Infineon, Owlet, Neoefect |
| Skin Patch  | Tech        | Eccrine systems, BioTelemetry, Epicore, PKVitality, Biolinq, Theranica, Gentag, iRhythm, Medtronic, Nemaura |

these devices can track in real time useful metrics (such as body fat estimates, blood oxygenation, etc.) that hitherto required the physical presence of a doctor or special equipment [33]. Hence, most wearable companies have only succeeded in flooding the wearable market with enablers of pervasive healthcare service delivery and not necessarily medical devices. This concern has questioned the reliability of these device in providing biased information that makes consumer’s resort into self-medication rather than seeking medical help [34].

Furthermore, the constant need for improved real-time p-health system, increase in preventive care, intuitive monitoring of patients’ compliance remotely (through real-time data collection and analysis), decrease in readmission rates, as well as acceptance of seamless real-time remote-based professional advice and treatment, and much more, also drives the wearable technology market volatility [29]. Real-time p-health system refers to the provision of real-time contactless medical support to users with specific time-sensitive conditions. Moreover, end users’ preference of a compact but reliable product (hybrid and multi-functional) that would integrate and fuse all functions seamlessly is also a factor propelling wearable technology development [29, 35].

In addition, demographic and social trends such as increased prevalence of chronic disease; rising average life expectancy, need to decrease length of hospital stay; higher ratio of seniors; larger proportion of patients requiring long-term care; etc. is also driving this technology [36]. Finally, the need to cut-down the global public and private expenditure on health estimated at USD 7.2 trillion in 2012 is also a critical factor driving accelerated advancement of the sensing wearable market [29]. With all the aforementioned factors and consequent advancement in Internet of Things (IoT), wearables are expected to bring about high growth opportunities in all sectors of the economy including healthcare as it was reported that the size of the wearable market grew from USD 1.4 billion in 2013 to USD 19 billion in 2018 [35].

IV. UNOBTRUSIVE WEARABLE DEVICE DESIGNS AND SENSING APPROACHES

Though wearable device market is experiencing a boom, yet the development of unobtrusive wearable devices for practical healthcare purposes is relatively slow [15]. This is relatively due to the infeasibility of brittle material and integrated circuit technology used in the production of the semi-conductors as well as the complex nature of human body requiring different monitoring devices to be attached to it at the same time [18]. Innovation in tele-health is closely linked to advancement in electronics technology as shown in Fig. 5 and Fig. 6 respectively. The core technologies of sensing wearable devices has evolved from water buckets and bulky vacuum tubes, to bench-top, and from portable devices with discrete transistors, to the recent small and compact wearable devices with integrated circuits [27].

![FIGURE 5. Timelines of Medical Devices with Technology Evolution representing the different milestones in wearable technological advancement](image-url)

Unobtrusive wearable device design is targeted at non-stop real-time measurement, monitoring, recognition and analysis of physical signs, behavioral patterns, physiological and biochemical activities of the user using some prede-
fined parameters. The most commonly measured signs are blood oxygen saturation ($\text{SpO}_2$), blood pressure (BP), heart rate, electrocardiogram (ECG), ballistocardiogram (BCG), posture, core/surface body temperature, etc. [37]. Unobtrusive wearable sensing is implemented as sensors worn by users (e.g. in the form of ear-ring, clothing, shoes, gloves, eyeglasses, watch, etc.), sensors embedded into an ambient environment, or as smart objects interacting with users (such as a chair [38], car seat [39], mattress and mirror [40], steering wheel [41], mouse [42], toilet seat, and bathroom scale [43]).

Over the years, unobtrusive wearables are designed with two sensing approach namely; capacitance-coupled sensing and photoplethysmography (PPG) [38]. Capacitance-coupled sensing is a sensing technique that uses a transmitter and a receiver electrode to measure the distances of nearby conductive objects by determining the capacitance between the sensor and the object (see Fig. 7). Once the transmitter is excited by a wave signal, the receiver picks up this wave. This method is deployed for measuring biopotentials like electromyogram (EMG), ECG, and electroencephalogram (EEG) [44]. The major challenge in capacitance-coupled sensing designs is high contact impedance due to indirect contact and capacitive mismatch basically caused by motion artifacts. However, with recent introduction of gradiometric measurement by Pang et al. [45], motion artifacts can be considerably reduced.

Conversely, photoplethysmography (PPG) sensing is a method that uses simple optical technique to detect volumetric changes in blood circulation. It is widely used to measure vital signs such as blood pressure, respiration rate, heart rate, $\text{SpO}_2$, etc. Varieties of unobtrusive and ubiquitous wearable devices have been developed over the years. Some are worn-on the body while others are implantable in the body using varied state-of-the-art emerging technologies, majority of which are applied in healthcare [7]. For example, wearables are deployed for neurological rehabilitation, monitoring of long terms chronic diseases, posture and activity monitoring of the elderly and the disabled, etc [46].

Generally, wearable devices for healthcare are categorized into portable devices, attachable devices, implantable devices, and ingestible devices [46] as succinctly presented in Table 4. Smart sensing and implantable devices helps to manage critical and chronic diseases, proactively diagnose health status, predict possible causes of ailment, and minimize post operative complications that requires patient’s readmission [47]. However, despite these pluses, statistical evidence reveals that implanted wearable devices accounted for 17% of acquired infections, 2-5% of hospitalization, and 20% surgical flaws, which is far from the desire to achieve flawless result [47] as earlier report [48].

The key enabling technologies behind unobtrusive wearable device design is summarized as MEMS; (Multi-sensor hybrid packages, Easy to implement, 9-axis IMU, and Sensor fusion software algorithms), with smart-optimized support of sensor power requirement and Long Term Evolution (LTE) for energy harvesting [49]. These core technologies have key performance indicators (KPIs) that play key role in the design and development of unobtrusive wearable devices. These indicators otherwise known as core performance parameters are the metrics for measuring re-inventiveness and performance efficiency of wearable devices in relation to technological advancement [15].

V. KEY PERFORMANCE INDICATORS IN UNOBTRUSIVE SENSING HEALTH WEARABLE DEVICES

The ubiquitous use of wearable devices is highly dependent on issues associated with its KPIs. According to authors [50], the key technologies that needs to be developed for improved implementation of unobtrusive wearable device is summed
as “MINDS”; miniaturization, intelligence, networking, digitization, standardization. However, Zheng *et al.* [3] in their work expanded the list of key technologies to include unobtrusiveness, security, energy-efficiency, robustness, and personalization. Thus, with advancement in technology, the parameters that determine and drives the innovation and performance of unobtrusive sensing wearable devices can be comprehensively summed as SUPER MINDS as seen in Fig. 8 namely; security, unobtrusiveness, personalization, energy-efficiency, robustness, miniaturization, intelligence, networking, digitization, and standardization.

### TABLE 4. Unobtrusive Wearable Devices for various Physiological and Physical Measurement

| Device Category | Examples | Monitoring | Physiological and Physical Measurement |
|-----------------|----------|------------|----------------------------------------|
| Ingestible      | Bionik Smart pill | Interstitial fluid Medicine | Glucose, pH and electrolytes (such as sodium), Medicine when drug reaches stomach with patch. |
| Implantable     | Pacemakers Tattoo | Cardiovascular signal Salivary Sweat | Heartbeat for treating arrhythmias. Monitoring respiration and pathogenic bacteria detection with tooth enamel Lactate, glucose, alcohol, and electrolytes (such as ammonium) with skin worn tattoo. |
| Attachable      | Wearable Skin Patches | Cardiovascular signal Body temperature Chemicals | Blood pressure and heart rate by measuring of ECG, BCG and pulse transit time with a thin, flexible patch. Sweat volume and sweat components like hydration, glucose, lactate, pH and electrolytes. Glucose and lactate in tear fluid. |
| Portable Device | Wrist-Mounted Devices | Cardiovascular signal Sweat contents Salivary contents Sweat contents Cardiovascular signal Salivary contents | Heart rate, blood pulse etc. (wrist band or watch). Glucose, sodium etc. (wrist band or watch). Lactate, uric acid and glucose etc. (mouth guard). Lactate and potassium etc. (eyeglasses). Heart rate (eyeglasses). Glucose and lactate etc. (textiles with electrode). Heart rate and temperature etc. (leg calf). Foot motion (footwear). Sleep, daily activity etc. (ring, necklace, and clip etc.). Step count and sitting time (belt worn on waist). ECG and direct current (belt worn on chest). |
| Portable Device | Head-Mounted Devices | E-Textiles | Others |
| Portable Device | Other Devices | | |

![FIGURE 8. Sensing Wearable Device KPIs based on advancement in core technologies indicating their interdependence in operations and developmental changes](image)

Fig 8 shows that the performance of an unobtrusive wearable device is a cumulative function of these core technology parameters as expressed in equation (1).

\[
\text{Device}_p = f[\sum (\Delta S_p, + \Delta U_p, \ldots + \Delta S_t_p)], \quad (1)
\]

where \(\text{Device}_p\) is wearable device performance, \(\Delta S_p\) is change in device’s security feature, \(\Delta U_p\) is change in device’s unobtrusiveness, and \(\Delta S_t_p\) is change in device’s standardization factor respectively.

However, a closer look at Fig. 8 indicates that these parameters are interwoven in their operations and development.

mental changes in determining the overall quality of experience (QoE) and QoS witnessed by users of these devices. This inter-relationship is technology-driven and multidimensional as changes in one parameter results in changes in another closely related parameter. For instance, the advancement in networking protocols and topologies is a function of response to changes in security architectures. Also, increase in digitalization is a function of better energy-efficient and conservative mechanisms. Based on this intertwined relationship, these parameters are condensed into 5 (five) major KPIs using discriminant factor analysis in response to 5G network. Hence, these KPIs are summed as “E-DISC”: Energy-efficiency, Discretization, Intelligence (Robust and Scalable), Customizable Standards, and Secured network. Therefore, the innovativeness and developmental transformation of any wearable device in response to technological dynamics is a function of these E-DISC parameters or technological factors as given in equation (2).

\[
\Delta \text{Wearable}_k = f[\sum (E_c, D_t, I_r, S_n, C_s)], \quad (2)
\]

with \(\Delta \text{Wearable}_k\) representing dynamic wearable innovation in response to technological advancement, \(E_c\) stands for device energy-efficiency rate, \(I_r\) is device’s intelligence robustness, \(S_n\) represents the device’s network security strength, and \(C_s\) is the device’s customization flexibility and interoperability. An empirical and introspective review of these KPIs in relation to 5G network provides an insight into pervasive issues in wearable devices that demands technological upgrades for seamless transition from 5G to B5G.

### A. ENERGY-EFFICIENCY

Energy-efficiency is the number of bits that can be transmitted per joule of energy. Energy-efficiency (minimal energy consumption) is critical in the design and optimal utilization...
of wearable devices for innovative healthcare delivery. Several innovative strategies have been developed over time to improve energy-efficiency of wearable device designs with the purpose of meeting advances in communication network as shown in Fig. 9. These innovative strategies include power management and energy-efficiency awareness approach and improving energy-efficiency of existing storage technologies [51], development of a novel structure of ZnCo$_2$O$_4$-urchins-on-carbon-fibers matrix [52], and development of commercial pen ink [53] to improve the efficiency of existing storage technology.

Also, scavenging energy approach from either ambient environment or human activities [54][55][56] using piezoelectric harvesters is gaining a stunning popularity in achieving minimal energy-consumption of wearable devices. With heterogenous network in place which emphasizes power savings, wider coverage, and increased capacity [57], wireless communication and data transmission via unobtrusive wearable devices will be significantly impacted upon to meet the much anticipated increase network traffic.

The information in Fig. 9 clearly indicates that an energy efficient B5G network leverages on deploying hardware solutions with massive Multi Input Multi Output (MIMO) antennas, millimeter wave frequency band for ease access and communication, full duplex and high network dense data rate for fast data transmission, and sleep modes for efficient resource usage. These characterizations are to ensure ultra-reliable low latency connectivity (URLLC) of devices. As such, an unobtrusive wearable device connected to such network is guaranteed real-time access and transmission of health-related data irrespective of data variability, velocity, or volume. Also, with energy-efficient B5G network, it is guaranteed that there will be reduction in the total cost of ownership [58] which is a critical cost component in determining the overall cost per unit product of any information technology resource [59], including wearables. TCO includes the initial costs to implement an IT project together with the continuing costs to maintain, modify, train staff, house, deploy, and provide infrastructure or any other cost associated with the project, including final decommissioning.

TCO is an estimate which includes all direct and indirect costs over the useful life of the IT-product which is commonly used in full cost accounting systems. This total Cost analysis is also known as life cycle cost analysis [59]. Also, TCO reflects not just the balance of the direct qualities of competing IT-products (price, functionality, reliability etc.) but also its relationship to broader set of technology platforms, as well as its ability to access market and community-based services and support. Hence, achieving energy-efficiency will facilitate minimization of TCO which ultimately will bring about reduction in the cost per unit product of unobtrusive sensing wearable devices as currently witnessed in the market (see Fig. 2 and Fig. 3) [28]. Hence, this will bring about reduction in the cost of unobtrusive sensing wearable devices as currently witnessed in the market (see Fig. 2 and Fig. 3) [28]. While improving energy efficiency, there is a constant flexibility by B5G operators to maintain reasonable trade-off between device overall performance and energy consumption level.

Digitization on the other hand, is closely connected to energy-efficiency as the analog signals from the body needs to be digitally analyzed, stored, and transmitted by these wearable devices. Maintaining accurate diagnostic measurement with minimal power consumption therefore requires critical innovative measures to be in place as inaccurate medical diagnosis can be fatal. Proper presentation of relayed message via wearable devices is key to increasing user-acceptability of such device. Hence, increase in digitization ensures that physiological and physical activities readings from wearable devices are presented in a user-friendly manner. Several novel attempts made in this regards include band-limited functions approximate reconstruction, heartbeats’ classification and compression using time-based approach [60]. Millimeter wave telecommunication as used in 5G provides extremely high speeds (Gbps) for Device-to-Device (D2D) communication [61].

### B. DISCRETIZATION

According to Brigante et al., the development of compact and lightweight wearable device with optimized layout design is proportionate to the increase in comfort derivable from such devices which is made possible by the size of processing electronics and inertia measurement unit (IMU) [62]. Hence, the more unobtrusive a wearable device is, the higher its user-acceptability and QoS. Miniaturization or discretization is also achieved via sensor inductive powering [49]. Discretization can be seen in capacitive coupling sensing method.
used for unobtrusive capturing of bio-electrical signals, as well as textile sensing for unobtrusive monitoring of physiological parameters, PPG for unobtrusive cardiovascular assessment [15].

The sophistication and miniaturization of sensors is largely dependent on the improvement of battery solutions, and advancement of wearable biosensors and material science to enhance durability and robustness in the future [47]. Hence, wearable sensors are expected to be inconspicuous and minimally cumbersome to reduce fears associated with putting on medical wearables in public. According to Andreau et al., the major challenge with unobtrusiveness especially as regards chronic implants are power management, stability of sensor in the long term, and biocompatibility of materials [47].

Consequently, with the advancement in material science and communication technology, improved implantable wearable device technologies has resulted in better management of many chronic diseases like cancer, hypertension, cardiac arrest, diabetes, etc [16]. According to Zheng et al., with the potentials of transient electronic technology, biocompatibility, biodegradability, and self-healability, fully integrated electronic and opto-electronic multi-functional system, an unobtrusive wearable device can retain its electronic functions, restore its electrical/mechanical characteristics after slight medical damage, robust in meeting complex human body needs, and possesses high ductility characteristics [15]. Transient electronic technology as an emerging technology emphasizes the need to develop systems that can be absorbed by human organisms and surrounding environmental micro-organisms at ultra-fast programmed speed without homeostatic imbalance and discomfort [64].

However, with miniaturization and unobtrusiveness comes the need to take into cognizance the health implication associated with long term exposure of vital organs of the body to ultraviolet rays emitted by these devices through constant usage [49]. Therefore, advancement in unobtrusiveness and miniaturization must continuously guarantee widespread user-acceptance through safety-sensitive innovations to avoid public disapproval [24].

C. ROBUST INTELLIGENCE

Wearable devices are designed to adjust to various environmental needs and responds to dynamic homeostatic of patients with accurate details. AI components allows autonomic functions such as sending alerts and taking informed support decision [20, 65]. AI also provides user-adaption and context-awareness features in wearable devices [66]. Several AI approaches developed and extensively applied in various healthcare applications include hidden Markov model, artificial neural networks, random forests, support vector machines, convolutional neural network, and neuro-fuzzy inference system.

The reduction of motion artifact of wearable sensors is still a challenging problem for the development of wearable system. Motion artifact of wearable sensors is due to the overlapping of wearable systems’ frequency band with the desired signal. Some of the proposed methods for reducing motion artifacts include adaptive neuro-fuzzy interference system (ANFIS), adaptive filtering method without additional sensors [67], adaptive noise cancellation method with the use of an embedded accelerometer [40]. Adaptive filtering method is not impressive in real-time application due to its extensive processing time. The lack of large-scale studies in real-world situations, need for individualized training data
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in supervised learning, and high rate of false alarms are some of the major obstacles that hinder the widespread adoption of sensing technologies in clinical applications [3].

Available statistics indicates that there is a significant increase in the adoption of AI [10], IoT [12], and mobile edge computing [20] in wearable devices for contactless health-care delivery and health-status tracking which has disrupted the global demand for wearable devices, and in turn impacted on the growth of the wearable market (see in Fig. 10). This upsurge in wearable device demand occasioned by disruptive is however not unconnected to the ultra-reliable low latency communication characterization that 5G networks offers as most of these devices are designed with capacity to run on 5G network.

D. SECURED NETWORK

Due to the expected roles 5G guarantees and its influence in changing lifestyle, the security of the network and reliability of the transmitted data over it is very important [1]. To deliver high efficiency and quality p-healthcare via unobtrusive wearables, efficient security and seamless network configuration are critical indicators that determines viable deployment [68]. The upsurge of wearable and other hand-held device’s development has generated multiple security concerns with privacy issues as the most palpitating and resurfacing problem [69]. Without adequate security, the transmitted data over wearable device via a wireless sensor network is vulnerable to different cyber-threats and attacks as seen in Fig. 11.

**FIGURE 11.** Security Threats and Attacks in 5G Networks

The challenge to guarantee security lies in three (3) aspects: how to protect user’s privacy (confidentiality), how to prevent the disclosure of patient’s data (trustworthiness), and the right of access to the system (authenticity) [44]. Hence, the improvement in data encryption, information confidentiality, and authentication strategies of wearables are of immense necessity. Data transmission security between wearable sensors for inter-sensor communications requires designing a key agreement for encryption. Various approaches has been proposed to handle this issue such as certificate-less conditional privacy-preserving authentication scheme for wireless body area networks big data services [70], Identity-based symmetric cryptography and asymmetric key cryptography for Body Sensor Network (BSN), use of impulse intervals (IPIs) [71] as shown in Fig. 12, and the use of PPG as bases for key agreement.

**FIGURE 12.** Illustration of secure inter-sensors communication for wearable health monitoring [71]

To further enhance security of data transmission between wearable devices and communication networks, 5G security technology strategies mostly deployed to track and curtail attacks are massive MIMO, physical layer coding, non-orthogonal multiple access technology, heterogeneous networks, millimeter wave communication, and full duplex networks [72]. Consequently, networking protocols and approaches utilized in the development of medical wearable device contributes significantly in guaranteeing security of vital medical information transmission between remote location and its eventual destination.

One of the most popular wearable technology networks is the BSN [73]. It is an inter-connectivity of allied technologies for the development of pervasive sensing for healthcare and other applications requiring widespread and persistent monitoring of physical, physiological, and biochemical parameters in any environment, without activity restriction, and any form of behavioral modification [73]. Sensing networks also include Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN), cellular networks (3G/4G/5G network, GPRS), Wireless Wide Area Network (WWAN). These are deployed in transmitting acquired data from wearable devices to data servers for storage and subsequent analysis and processing [73].

The major challenges of wearable networks include network security, network topology optimization, multiple sensor fusion, user mobility, and communication protocols for energy-efficient transmission [73]. Other issues of consideration include guarantee of QoS, transmission power, reliability (i.e., error control), latency, and bandwidth reservation [74]. Ultimately, wearable device for innovative p-
health will depend largely on incorporating supreme-built-in security paradigms, with flexible network mechanisms, and AI embedded security automation that requires minimal human intervention to retain its patronage from users.

E. CUSTOMIZABLE STANDARDS

Customization of wearable device for innovative healthcare delivery entails tweaking the device ergonomics, sensor calibration, disease detection, medical diagnosis, and treatment to meet up with technological dynamics while satisfying the varied ecstasies and demands of the targeted market audience. In 5G networks, tracking an individual’s physiological (oxygen level, body temperature, ECG, etc.) and physical (activity, posture, etc.) signs with varied details/pattern between devices and cloud-based platforms at various locations with the goal of guaranteeing precise personalized management, requires seamless data transmission and optimized intelligence from distributed database [36]. Customization to each user’s needs and specification therefore demands an intuitive, robust, and scalable interoperability across health service platforms.

Reviewing the existing interoperability protocols as standard procedure in the design and development of wearable device that meets 5G network demands is crucial in the wave of geometrical increase in cyber-attacks and security vulnerabilities across the global due to the premium attached to privacy of health records.

Despite the proliferation of wearables, statistics shows that there are only few interoperable standards available for evaluating the accuracy and reliability of health wearable devices. Among notable ones are ISO/IEEE 11073 [71], an extension of ISO/IEEE 1103 to accommodate wireless wearable devices at home [68]. Recently, the X73PHD standard (a micro-controller-based platform with low-voltage and low-power constraints) was established [68]. Though standardization process is often time-consuming and complicated, there is the urgent need to improve on the existing standards to meet demands of disruptive technologies and guarantee safety of users as 5G unwinds and B5G emerges with promises of more flexible and user-friendly options such as open-networking in radio access networking (O-RAN) across multiple support services.

Therefore, wearable designs that will operate in B5G networked environment for future p-health care delivery should consider meeting the standard requirements for integrating a device into a networked control system architecture namely dependability, interoperability, scalability, and composability (DISC). Composability refers to modularity of subsystems design for easier integration. Scalability refers to extensibility of the system to accommodate emerging functionalities due to dynamic operational changes in the environment. Hence, scalable and composable architectures allows for building of operational environment that not only supports dynamic and flexible changes, but also adaptive behaviours under resource and timing constraints. On the other hand, interoperability and dependability emphasizes the need for flexible integration of components and reliable (fault-tolerant) output respectively.

VI. B5G NETWORK AND WEARABLE DEVICE TECHNOLOGIES: FUTURE DIRECTION

Unobtrusive wearable device has contributed immensely to p-health service delivery due to advancement in its underlying technologies. However, data from these devices that are applicable for clinical trials has not genuinely solved real-world practical concerns as its fails to meet up with expected requirements [75]. This according to authors [75] is due to bias (selective) and under-reporting of outcomes, the use of proxy, complex, and prejudiced endpoints for predictions, failure of incorporating end user’s viewpoint in device designs, misleading and ambiguous suggestions, inconsistent and multi-variant outcomes, use of complex metrics and scales for result interpretation, amongst others. Thus, it undermines the reliability of the results from these devices. Such unreliable results create anxiety on its users and affects the reliance on such results by both the end-users and the physicians in drawing factual conclusions about medical decisions and treatments. Thus, poor data representation for digital health management is a critical issue that demands a closer consideration in wearable designs for innovative healthcare delivery. Furthermore, wearable device makers need to be concise and clear about how these devices should be used.

Also, most of the applications deployed on wearable devices for tracking and monitoring different physical and physiological parameters have not been cleared by the relevant regulatory and medical agencies due to several reported cases of inconsistent and unreliable readings and recommendations from the devices. These unreliable recommendations have resulted in patients seeking unwarranted medical attention. To be precise, a study shows that only 11.4% of 264 patients who received abnormal pulse reading from their apple smartwatch sought medical cardiovascular diagnosis [75]. These statistics reveals the extent these users trust the readings from these devices.

Hence, qualitative and unbiased data collection techniques, inclusive participation of end-users in device design process, transparency, and trustworthiness in reporting outcomes, and self-explanatory but delimited sensitivity consciousness when transmitting certain information to users to avoid abuse, agitations, and additions, are keys to remedying these identified flaws. This will help in translating health record meant for clinical trials into real time real-world application. By incorporating these essentials in the design and development process of wearable device and integrating it into B5G network capabilities, these identified flaws can be remedied.

The ultimate goal of 5G and B5G wireless network is ultra-fast network connectivity and data transmission (speed to support disruptive technologies of 10Gbps and above), incredibly low latency (miniaturized and energy-efficiency), substantial rise in base station’s efficiency (especially security), and improved QoS through reliable feedback [2].
implies that 5G network and beyond focuses on delivering IT-products that runs seamlessly and secured across terminals irrespective of destination. Hence, the critical issue demanding innovative engineering is the development of unobtrusive wearable device with improved data security, privacy, and the digitalization of healthcare data [76]. Leveraging on the potentials of B5G in transforming healthcare delivery, the future of wearable healthcare device for p-health that will align with B5G network is anchored on three (3) interconnected core pillars; speed (personalized standards), smartness (secured networks with robust intelligence), and smallness (energy-efficiency and discretization) as expressed in equation (3) and depicted in Fig. 13.

\[
\Delta Device_p = f[\Sigma(Ss_p, Sm_p, Sp_p)],
\]

(3)

where \( \Delta Device_p \) is B5G wearable device performance, \( Ss_p \) is device size, \( Sm_p \) is device smartness and \( Sp_p \) is device speed of feedback. From Fig. 13, AI is at the hub of the operations of B5G wearable devices in transforming outcomes into usable assets for reliable medical decisions. Therefore, equation (3) can be re-expressed as

\[
\alpha Device_p = \Delta Device_p + \Delta \Theta_{ai},
\]

(4)

with \( \Delta \Theta_{ai} \) representing the dynamic impact factor of AI in the operations of B5G wearable device. With increase in trustworthiness and transparency in the design and development of AI-products such as unobtrusive wearable device, the inherent lapses in the existing wearable device can be curbed.

A. SMALLNESS

The expected wearable technology in 5G and B5G environment is the creation of intelligent virtual power-plant that optimizes resource usage, incorporates efficient-energy usage, compact and precise production, and trading in a highly secured channel. As seen in Fig. 13, actualizing smallness is largely dependent on increased energy-efficient paradigm, discretization, and improved standards. Hence, energy-efficiency and its derivatives in wearable device is based on heterogeneous B5G network with enhanced capacity, coverage, and power savings [13] for reliable transmission of health data.

The parameters for checkmating energy efficiency in 5G and B5G network include but not limited to sleep mode [77], high network data rate [78, 79], dense small cell deployment [80], full duplex [81], massive MIMO antennas [80, 82], millimeter-wave frequency band [83]. Millimeter wave telecommunication as used in 5G provides extremely high speeds (Gbps) for D2D communication [84]. The major issue in millimeter wave is that at higher frequency bands, there is signal attenuation which limits the strength of the signal. Also, oxygen molecules and water vapors affect mm-wave energy. Hence, maintaining a trade-off between performance and energy-efficiency is considered very critical in the development of wearable device that will meet QoS [1]. Channeling research efforts in addressing the identified lapses inhibiting miniaturization to gain speed is necessary.

To address issues relative to surrogate and composite outcomes, wearable device designs should focus on real-time patient-relevant and expert agreeable outcomes. To achieve this, AI-driven wearables should consider the correlations and inter-relationships of aggregated features in datasets used for predicting results and making recommendations. This feature aggregation principle should be done with full consultation of relevant medical experts and following established clinical records and procedures. This will further ensure that the problem of non-inclusion, non-representativeness, lopsided and biased wearable device outcomes is avoided. Only with 5G and B5G can the domain of AI devices transit from artificial normal intelligence to real human intelligence where irrationality is blended with rationality in proffering
reliable dynamic solutions in a complex environment like the human body. With this aggregation of features through feature engineering, low computational cost is guaranteed which in turn translates to more speed and encourages more unobtrusiveness in wearable device. This simplicity in wearable designs will further motivate hybrid digital and analog antenna development [24] for ultra-reliable connectivity.

**B. SMARTNESS**

The blending of disruptive technologies that are capable of meeting user traffic (security), dynamic demand-oriented services (intelligence) and scalable growth of IoT and Industrial Internet of Things (IIoT) (robustness) is considered the core strengths of 5G and B5G networks. Smartness and security are two inseparable interwoven components because smartness is a function of high-security alertness and sensitivity in situation-based decision-making with high precision. Integration of large-scale IoT and IIoT with new technology concepts that demands high precision feedback, real-time proactive decision-making, ease of use, and optimum confidentiality and trustworthiness; creates smartness-based security constraints [65, 85] especially in unobtrusive wearable devices. These characterizations is achievable in a system driven by AI as shown in Fig. 13.

According to International Telecommunication Union (ITU-T), security features in B5G security architecture are divided into separate architectural components [86]. This is to guarantee systematic end-to-end security of services, help in planning means to assess the security of current networks, and facilitate new security solutions, in a bid to improve the alertness and rationality of the devices that uses these security models. Thus, security in B5G network is focused on supreme-built-in encryption (security as software); versatile security systems (AI-based security and applying AI in cyber-security); and various manufactured based-automation (security automation) [87]. This has resulted in the development of various AI-based intrusion detection system for wearable devices [88, 89, 90, 91]. This enhances that data confidentiality and privacy is maintained in wearable device thereby increasing trustworthiness and reliability of the end-users in the system.

Smartness also entails real-time transmission of intelligent and secured information remotely between the end-users and its needed destination; detection of data patterns from large-scale dynamic sources, and recommendation of intelligent action to be taken forthwith via artificial intelligence paradigms [89]. Hence, wearable device that will operate effectively in 5G and transit seamlessly into B5G should consider incorporating features that not only mitigate futuristic threats, but also provide trustworthy real-time intelligent feedback that will satisfy users’ expectations [92]. With internet of humans, a novel concept in healthcare that connects, monitors, and records patients’ health status in realtime via internet and other disruptive technologies [9], rapid medical response is guaranteed through B5G.

Leveraging on the potentials of AI and B5G, the use of complex scale and ambiguous relaying of results that instills anxiety in end-users of wearables can be curbed. AI-driven and B5G compliant wearable device designs should also incorporate features for relaying user-centric results that are concise, self-explanatory, and specifies asymptotic condition rather than average score/ratings. Furthermore, there should be a paradigm shift from wearable device result interpretation that are statistically significant to results that are clinically beneficial to serve as benchmark for predicting the future. With AI-based security approach, information censoring can be achieved in wearable device. Hence, B5G compliant wearable device should consider delimiting transmission of precarious medical details to end-users and leverage on the edge network to transfer such complex prescriptions to medical practitioners to avoid frustration and self-medication.

**C. SPEED**

Due to constant high demand on latency, computation resource, and efficiency, even 5G networks may not be able to help the development of wider application of future technologies [93]. Hence, the discretization, networking, and standardization of antennas and sensors to be used in B5G must correspond to the speed of data transmission across connected devices including unobtrusive wearable device. Speed in this context cuts across network bandwidth (the rate of data transfer in any given network signifying its capacity), throughput (the amount of data moved at any given time) and latency (time taken for a data packet to get its intended destination).

Notably, antenna from previous mobile communication technologies (1G-4G) are passive and uses capacitors, conductors, and metal rods which inadvertently affected data transmission speed across connected devices including wearables. However, 5G and B5G compliant antennas are active in nature with high speed (frequency ranging between 30 to 300GHz), low latency (up to 1ms to 100µs end-to-end device latency), bandwidth (connection capacity measuring in multiples of Gbps) and possesses AI-based security features [94, 95]. Other effective approaches deployed to boost performance, coverage, reliability, and user-experience in 5G and emerging B5G network include but not limited to advanced antenna system (AAS), beamforming, and MIMO strategies [96].

These characteristics undoubtedly will boost real time streaming and transmission of reliable data (structured and unstructured) over wearable device between end-users and medical experts thereby reducing ambiguity hitherto experienced in results’ interpretation of previous devices due to weaknesses in their underlying communication technologies such as network traffic, propagation delays, hardware issues, etc.

Therefore, reinventing more innovative approaches to enhance antennas performance to achieve more speed and incorporating such features into wearable device will help in actualizing innovative healthcare delivery. Also, to meet user-expectations, wearable devices should be designed to effi-
ciently communicate with antennas with geometrical adjustment parameters to obtain multi-band response. Furthermore, deployed antennas should be MIMO-based with mmWave spectrum. Lastly, there is the need to take adequate steps in preventing and/or protecting signal loss caused by rain, fog, or snow which is a clog in communication technology advancement. Addressing the outlined issues will translate into making wearable device an asset for actualizing innovative p-healthcare delivery.

VII. POTENTIALS OF B5G KPI TO SUPPORT WEARABLE DEVICE TECHNOLOGY

Consequent upon the unwinding of the 5G, research efforts were moved to focus on practical implementation of B5G or 6G with the target year as 2030 [97]. It is argued by researchers that B5G will affect all sectors. However, this section is targeted at the health sector only with emphasis on wearable devices. For instance, Kazim et al [92] opined that ‘unobtrusive and noninvasive measurements using RF sensing, monitoring, and the control of wearable medical devices are the areas that would potentially benefit from B5G’. Thus, B5G is seen as an enabler for future p-health use-cases such as wearable device technologies.

Moreover, the 5G regime has been reviewed by researchers as not capable of meeting the future use-cases by the year 2030 [97]; thus, working towards the B5G regime such as the 6Genesis Flagship program in Finland [61, 98] will amount to being proactive in research and development of innovative wearable healthcare device. The identified KPIs (smartness, speed, and smallness) as discussed previously are further decomposed into latency, mobility, connection density, energy efficiency, peak data rate, spectrum efficiency, user experience data rate, and area traffic capacity [97] to spotlight specific differences in 5G and B5G in addressing the inherent challenges in the existing wearable device. In the following subsections, the review examines some of distinct characteristics that is envisaged to support the future wearable device technology.

A. BEYOND MM-WAVE COMMUNICATION IMPACT ON WEARABLE DEVICE TECHNOLOGY

Existing 5G technology operate at extremely high frequency such as the mmWave [99]. However, B5G or 6G is expected to leverage on the higher spectrum technologies such as terahertz and optical communication [61, 100]. mmWave signals have been shown to be susceptible to challenges such as severe path loss, directivity, narrow beam-width, and sensitivity to blockage [101]. Moreover, the IEEE 802.15.6-body area networks (BANS) protocol designed for on-body communication limits the usage of wearable devices as they suffer signal connectivity degradation due to energy constraints. Recent works suggest the integration of “intelligent walls” [92] to aid the collection of weak signals from wearable devices and interlink with another wearable device in the vicinity. This will further encourage the integration of communication for machine learning schemes into smart wearable device [102] to improve its responsiveness and derivable utility.

B. SUPPORT FOR THE INTERNET OF NANO-THINGS AND INTERNET OF BODIES VIA SMART WEARABLE DEVICE TECHNOLOGY

Support the Internet of Nano-Things and Internet of Bodies through smart wearable devices and intra-body communications achieved by implantable nanodevices and nanosensors with extremely low power consumption (on the order of picowatts, nanowatts, and microwatts) [99]. Network generation trend from 4G to 5G and beyond, indicate a shift toward the comprehensive realization of internet of things, nano-things, bodies, and wearables [99]. Consequently, future wearable networks will need to transfer much greater amounts of data at much higher speed [100]. This has given rise to new paradigm known as the Internet of Medical Things (IoMT) [92] in a bid to achieve innovative p-healthcare delivery by leveraging on the potentials of B5G technology.

C. NETWORK EFFICIENCY IMPACT ON WEARABLE DEVICE TECHNOLOGY

In addition, unlike the 5G network with 99.999% reliability and 1ms latency, the B5G networks such as 6G is expected to guarantee continuous availability (99.99999% reliability at ultra-low latency (100µs) [100]. Future wearable devices will require more stringent end-to-end latency as well as tighter reliability boundaries [103]. To become ubiquitous beyond 5G, wearable device designers and manufacturers should consider creating a balance between open innovation and seamless connectivity of their products [35]. This will enhance end-users trust and reliability of the information relayed and results from these devices.

D. DIVERSE MOBILITY MANAGEMENT IMPACT ON WEARABLE DEVICE TECHNOLOGY

The mobile Internet and Internet of Everything (IoE) are two drivers for 6G that will support holographic and high-precision communications for tactile and haptic applications (e.g., the tactile Internet) [104] to provide a full sensory (i.e., vision, hearing, smell, taste, and touch) experience. This requires processing a very high volume of data in near real time, with extremely high throughput (approximately Tb/s), and low latency [99] which undoubtedly is guaranteed by B5G and essential for future wearable device in handling, processing, and transmitting large chunks of data with velocity, volatility, and variability.

E. MULTIPLE DATA ACCESS TECHNOLOGY IMPACT ON WEARABLE DEVICE TECHNOLOGY

Wearables are generally seen as subcategory of IoT. They can connect to other devices to collect or share data [36]. In addition to real-time display of information allowing users on-the-spot access to information, wearables could offload
data to the cloud or other devices that can handle more computationally intensive analysis [68]. Beyond 5G, wearable devices will leverage more on multiple access to data such as the cloud, and other large storage compliant servers [105]. Hence, future wearable device is expected to participate in the integration of “things connectivity” to enhance its performance and derivable utility by its end-users rather than an isolated physical and physiological changes determinants which is the current practice.

VIII. CONCLUSION

In this work, an introspective review of wearable device technologies KPIs is presented in relation to its transition into B5G network in a bid to deliver innovative healthcare. The overall performance, perceptibility, and people’s acceptability of these devices is based on the level of transformative integration of these KPIs in their design in response to social demands. Though, significant improvements have been achieved in the design and development of these devices in response to social and economic dynamics, there is need for improved practical implementation and incorporation of more innovative and eco-friendly solutions into these devices to boost their performance for seamless transition into the emerging generation network, the B5G. These identified wearable device KPIs namely energy-efficiency, discretization, robust intelligence, secured network, and customizable standards are interwoven in their operations with AI at the hub in delivering smart, speedy, and reliable information that are assets for personal and medical purposes.

Currently, the wearable market is experiencing a global technological boom due to increase in demand for contactless p-health and other socio-economic factors. However, there are numerous technological issues and challenges confronting the performance of wearable device that requires urgent attention. These challenges cuts across wearable reliability issues such as smartness (usability safety), dependability (trust of relayed information), availability (cost-effective real-time connectivity), and maintainability (error control) as well as real-time issues such as security (standardized interoperability), and speed (wider coverage and responsiveness). Addressing these challenges through intensive research and development effort will result in seamless transition of wearable device technologies from 5G to B5G.

With the unique characterization that B5G network is expected to offer, the emerging transient technology paradigm of wearable device for healthcare will be crystalized to operate smoothly in an eco-friendly environment where increase in speed of secured information transmission in a smart manner is guaranteed to meet and exceed end-users’ expectation. This is only possible as the gap between research and innovation in wearable technologies and that of communication networks is bridged through practical implementation of ideas that will translate wearable device into irresistible assets for innovative p-healthcare delivery.

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