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SYSTEMS-LEVEL QUALITY IMPROVEMENT

Real-Time Fault-Tolerant mHealth System: Comprehensive Review of Healthcare Services, Opens Issues, Challenges and Methodological Aspects

A. S. Albahri[1] · A. A. Zaidan[1] · O. S. Albahri[1] · B. B. Zaidan[1] · M. A. Alsalem[1]

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Abstract

The burden on healthcare services in the world has increased substantially in the past decades. The quality and quantity of care have to increase to meet surging demands, especially among patients with chronic heart diseases. The expansion of information and communication technologies has led to new models for the delivery healthcare services in telemedicine. Therefore, mHealth plays an imperative role in the sustainable delivery of healthcare services in telemedicine. This paper presents a comprehensive review of healthcare service provision. It highlights the open issues and challenges related to the use of the real-time fault-tolerant mHealth system in telemedicine. The methodological aspects of mHealth are examined, and three distinct and successive phases are presented. The first discusses the identification process for establishing a decision matrix based on a crossover of 'time of arrival of patient at the hospital/multi-services' and 'hospitals' within mHealth. The second phase discusses the development of a decision matrix for hospital selection based on the MAHP method. The third phase discusses the validation of the proposed system.

Keywords Telemedicine · Fault-tolerant · mHealth · Healthcare services · Triage · Server failure · Medical Centre failure · Network failure · Sensor

Introduction

With the emergence of new technologies, telemedicine has become the centre of interest of the research community [1]. Telemedicine is a remote medical practice in which different performing actors can cooperate and collaborate to diagnose or treat a disease by means of telecommunication and information technologies [2]. The architecture of telemedicine is based on three tiers. Tier 1 is sensor-based, Tier 2 is gateway-based and represents mHealth (Tiers 1 and 2 denote the client side) and Tier 3 represents the medical centre server side that is connected to distributed hospital servers [3–8]. Healthcare services in telemedicine are based on a client–server architecture [4, 7, 9], and this is the key factor that enables telemedicine to build up a diagnosis, provide preventive or post-therapeutic medicinal checking and monitoring, perform therapeutic acts, and recommend drugs [10], all of which offer empowerment, superior personal satisfaction and reduced cost of administration to patients with chronic diseases, such as cardiovascular infection, diabetes, chronic respiratory maladies and cancer [11, 12]. The attractive part of telemedicine architecture is mHealth, which is considered the real engine that manages the traffic movement of healthcare services between other parts (Tiers 1 and 3).

mHealth involves the use of and capitalization on a mobile phone's core utility of voice [13] and short messaging service (SMS) together with complex functionalities and applications,

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✉ A. A. Zaidan
aws.alaa@gmail.com; aws.alaa@fskik.upsi.edu.my

A. S. Albahri
ahmed.bahri1978@gmail.com

O. S. Albahri
osamash89@yahoo.com

B. B. Zaidan
bilalbahaa@fskik.upsi.edu.my

M. A. Alsalem
mohammed.asum@gmail.com

[1] Department of Computing, Universiti Pendidikan Sultan Idris, Tanjong Malim, Perak, Malaysia

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including general packet radio service (GPRS), third and fourth generation mobile telecommunications (3G and 4G systems), global positioning system (GPS) and Bluetooth technology. However, the rapid and wide-scale introduction of mobile technologies in healthcare has resulted in an emerging area of mHealth. mHealth offers the potential for combining sensor networks and information to help provide healthcare services to patients. A comprehensive review of literature is essential in highlighting healthcare service provision in telemedicine applications, and mHealth needs to be scrutinized in detail. Telemedicine benefits from a vast bibliography, but practical challenges remain in organizing risk management in the context of continuous improvement of healthcare services through mHealth [14]. The rising costs of healthcare services and the aging of the global population add to the restrictions in applying telemedicine networks to the delivery of common healthcare services [15–17]. The increase in the number of patients is driven by various challenges and produces many issues related to healthcare services [3, 9]. further investigations need to highlight the challenges and open issues in providing healthcare services through mHealth in telemedicine applications. In addition, the methodological aspects of providing healthcare services within mHealth need to be emphasised to ensure a continuous provision of healthcare services to patients and overcome related challenges in telemedicine. The literature review framework for the real-time fault-tolerant mHealth system is shown in Fig. 1. The rest of this article consists of three sections. Section "Comprehensive Review" provides a comprehensive review of past studies. Section "Methodological Aspects" presents a discussion of the methodological aspects of three distinct and successive phases. Section "Conclusion" provides the conclusion.

Comprehensive review

This section presents a detailed literature review. A systematic review protocol for telemedicine application is presented in the following section.

Systematic review protocol

The systematic review protocol that was used in this research is presented in this section. The systematic review method, information sources, study selection, search and eligibility criteria, data collection and taxonomy analysis are presented in subsections.

Method

The most significant keywords in the scope of this study are 'telemedicine', 'triage', 'priority' and 'sensor'. Other studies on telemedicine, such as surveys and reviews, were excluded. The scope was limited to English literature but considered all health-related areas. Three digital databases were used to conduct the search for target articles: (1) the Science Direct database offering access to science, technology and medical (STM) journal articles, (2) the IEEEXplore library of technical literature in engineering and technology and (3) the Web of Science (WoS) service that indexes cross-disciplinary research in sciences, social sciences, arts and humanities. The rationale behind this selection is to cover medical and technical literature and provide a broad view of researchers' efforts in a wide but relevant range of disciplines. Study selection consisted of searching for literature sources, followed by three iterations of screening and filtering. The first iteration excluded duplicate articles and collected only those in the last six years (2012–2017) by using Mendeley software. The second iteration filtered the articles by scanning the titles and abstracts and excluded articles that are beyond the study domain. The third iteration filtered the articles after a thorough full-text reading and excluded articles beyond the study domain and out of the eligibility criteria. All iterations applied the same eligibility criteria, followed by screening and reviewing. The search began in January 2017 for Science Direct, IEEE Xplore and WoS databases via their search boxes. In this search, a mixture of the following keywords was used: 'medical system', 'telemonitoring', 'E health', 'telemedicine', 'telehealth', 'healthcare services', 'remote monitoring', 'mobile doctor' in different variations combined by the 'OR' operator, 'triage' in different variations combined by the 'AND' operator, 'priority' in different variations combined by the 'OR' operator and 'sensor' in different variations combined by the 'AND' operator. The exact query text is shown at the top of Fig. 2. The options in each search engine were used to exclude book chapters and other types of reports other than journal and conference articles because we deemed these two venues as the most probable to include up-to-date and proper scientific work relevant to this survey.

Eligibility criteria

Each article that met the criteria listed in Fig. 2 was included. This study set an initial target of mapping the space of research in the title into a general and coarse-grained taxonomy composed of three categories. These categories were derived from a pre-survey of literature with no constraints (Google Scholar was used to obtain a first view of the landscape and directions in literature). After the initial removal of duplicates, articles were excluded in the iterations of screening and filtering when they did not fulfil the eligibility criteria. Examples of exclusion reasons includes (1) the article is non-English; (2) the article is a survey or a review; (3) the focus is on a specific aspect of telemedicine application, such as sensors and networks; and (3) the target is general telemedicine technology,

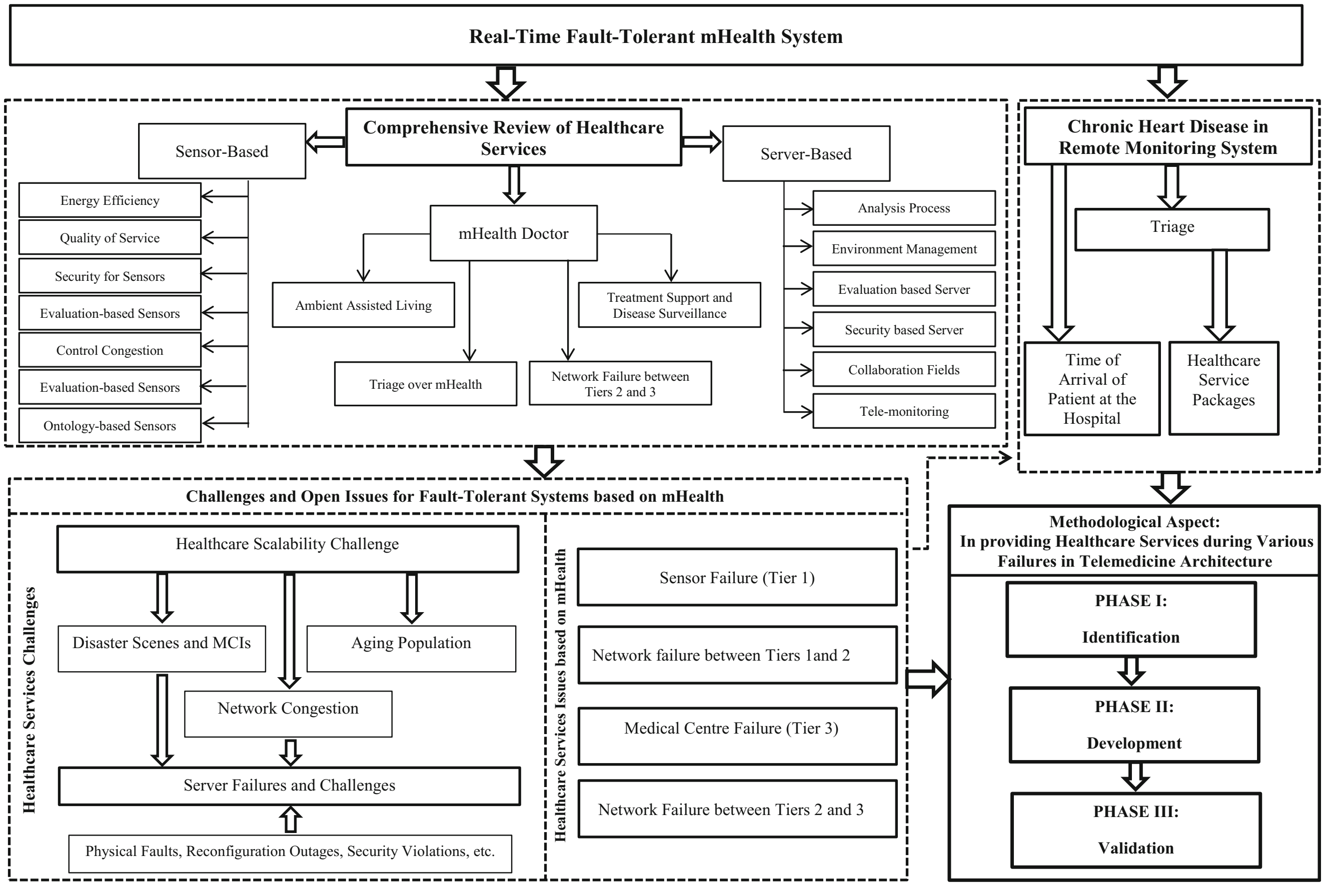

Fig. 1 Literature review framework

but we focus on healthcare services, patient prioritization, patient triage, disaster management, network failure, sensors in telemedicine and security of telemedicine [18–27].

Data collection

To simplify the filtering process, all included articles were read, analysed and summarised with their corresponding initial categories and saved as an EXCEL® file and a Mendeley® library. Full text reading for all articles was performed by the authors. The numerous highlights and notes on the surveyed studies and a running classification of all articles allowed for the creation of the proposed taxonomy. The comments were recorded as hard- or soft-copy versions according to each author's style. This process was followed by another process of characterisation, description, tabulation and conclusion of essential findings. These findings are provided in supplemental materials to offer a complete reference for the taxonomy results.

Taxonomy results

The initial search resulted in 3064 articles, among which 657 were from WoS, 911 were from ScienceDirect, and 1496 were from IEEEXplore. The time span was 2007–2017. Two articles from WoS could not be downloaded due to accessibility issues. A total of 1612 papers were collected for the last six years only (2012–2017). Sixty-two articles were duplicates in the three databases, resulting in 1550 papers. After screening the titles and abstracts, another 1264 articles were excluded, resulting in 286 papers. A total of 164 articles were excluded via full text reading, leaving 122 articles in the final set. These papers were read thoroughly to obtain a general map of the conducted research on this emerging topic. The final articles were classified into three major categories: Tier 1, Tier 2 and Tier 3. As a result of the taxonomy analysis, specific patterns and general categories were identified for healthcare services in the telemedicine area. The mapping and domains of telemedicine applications are illustrated in Fig. 3.

Tier 1

The data collection module gathers information from each source and receives vital signs that provide a description of the patient's pathological condition. This category includes the sensor-based domain and will be explained in detail in the next section.

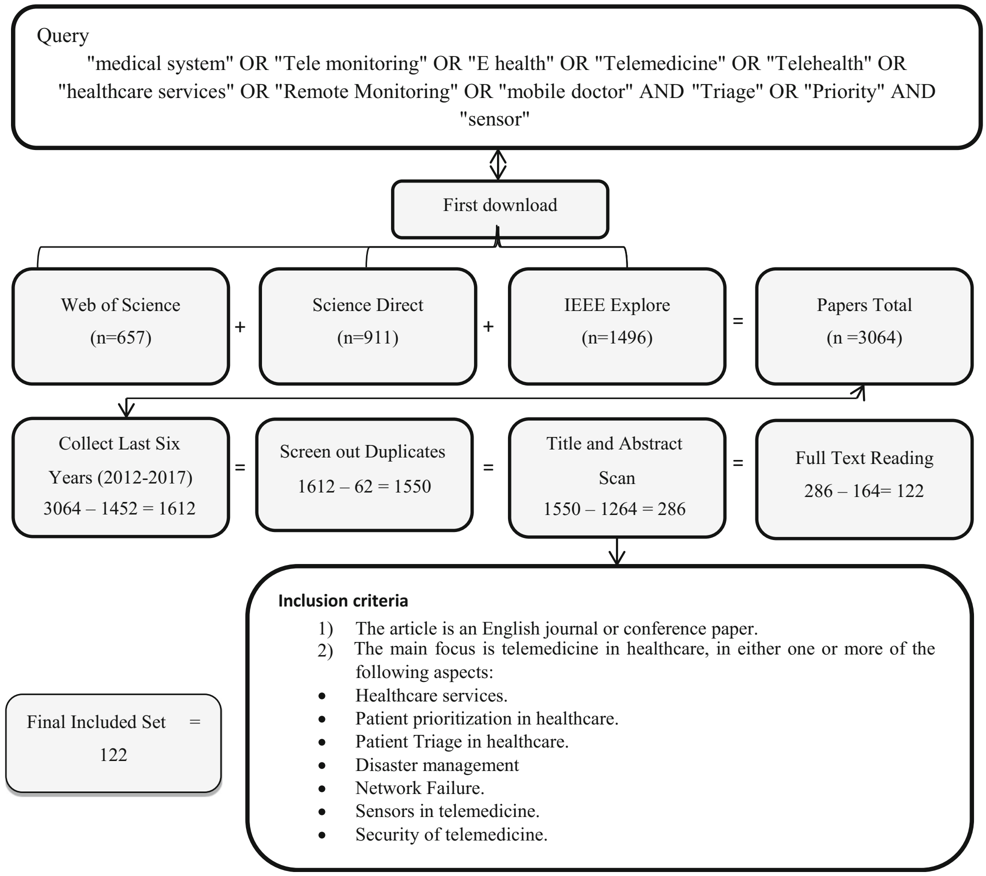

Fig. 2 Flowchart of study selection, including the search query and inclusion criteria

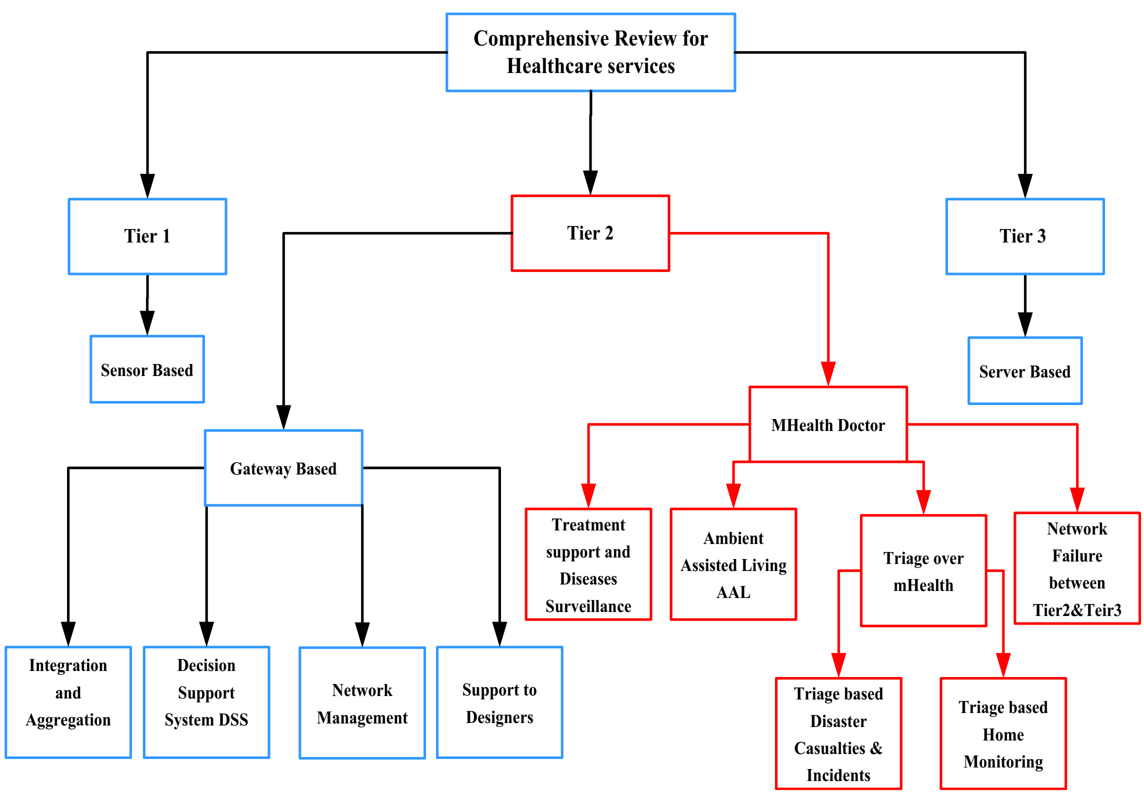

Fig. 3 Taxonomy of research on telemedicine applications

Sensor based

Sensors are described, and the issues and technologies of sensors in telemedicine applications that can provide continuous and reliable health monitoring for patients are summarised. Wireless body area networks (WBANs) are composed of tiny intelligent wireless sensors that are responsible for gathering a patient's vital signs and transmitting vital information [28]. This domain consists of seven areas, namely, energy efficiency, quality of service (QoS), security for sensors, evaluation-based sensors, control congestion, reliability and ontology-based sensors.

The first area in the sensor-based domain is energy efficiency. The high energy efficiency and high transmission reliability of directional antenna technology offer choices for wireless sensor networks, especially in battery-operated networks [29, 30]. Studies on energy efficiency examined traffic routing and transmission data packets. Studies on transmission data packets focused on obtaining high energy efficiency and robust data transmission, minimising power consumption, prolonging network lifetime and guaranteeing on-time task execution by increasing the predictability of systems [29–34]. Other studies presented priority-based time slot allocation schemes for WBANs to achieve energy efficiency [35–37]. A green-cloud-assisted healthcare service for WBANs that considers the sensing frequency of the vital signs of various parts of the human body and data transmission was presented in [38]. Traffic routing, which guarantees reliable traffic dissemination and customised channel access for 'intra-body and inter-body communication', was presented in [39]. The second area in the sensor-based domain is QoS. Given that the environmental and physiological data gathered by multimodal sensors have various significance levels, the provisioning of QoS for the data of sensors in WBANs is a critical issue [40]. Studies in this domain focused on QoS for WBANs. The provisioning parameters to extract QoS performance metrics, such as packet loss rate, throughput, queue length and delay, were presented in [40–44].

The third area sheds light on sensor security. Efficient and secure data aggregation is important to ensure users' privacy and data delivery integrity [45]. Studies that focused on the security and privacy of sensors were conducted in many directions. A prototype of a biomedical sensor application implementing TinyECC to secure wireless communication among sensor nodes was presented in [46]. Another study focused on the secure logging of the information gathered from nodes in a wireless sensor network (WSN) [47]. Multi-level security, including a distance bounding test and encryption, for avoiding long-distance attacks was presented in [48]. Encryption of compressed data and protection of integrity were achieved by a cryptographic hash algorithm presented in [45] to preserve data integrity. A comprehensive Integrating the Healthcare Enterprise (IHE)-based X73PHD extension containing additive layers adapted to many mHealth and eHealth applications was proposed in [49]. In the evaluation-based sensor area, [50] presented a performance evaluation of the IEEE 802.15.6 standard in terms of power consumption, latency, packet delivery rate and packet breakdown at the MAC layer while satisfying the ISO/IEEE 11073 requirement. Another study evaluated this standard when applied on various sensors from the Cane Network (CANet) eHealth project [51]. An assessment of the effectiveness of wearable health monitoring devices in reducing primary-care patient load was conducted in [52]. An evaluation of miniature wireless vital signals for potential trauma triage in intensive care units was presented in [53].

In the control congestion area, common problems of congestion in many data networks, such as WSNs, result in packet loss, increasing end-to-end delay and excessive energy consumption due to retransmission [54]. In [55], a protocol to detect congestion with multiple biosensors that are dependent on the type 2 fuzzy logic system was proposed. An identical study [56] proposed a control protocol to monitor ECG signals remotely, change the rates of transmitted ECG information and assign priority to patients. A priority-based congestion avoidance scheme called PCAH that avoids the congestion problem and provides an efficient mechanism to save energy was proposed in [57]. The Healthcare Aware Optimized Congestion Avoidance and Control Protocol or HOCA was proposed for healthcare applications in [58]. Active queue management and multi-path QoS-aware routing were used. Additionally, [54] proposed an optimized congestion management protocol for HWSNs with two stages: (1) avoiding congestion by scheme (AQM) and providing QoS and (2) controlling congestion by using three mechanisms.

In the reliability area, WBANs face critical challenges in terms of reliability for the communication of physiological data gathered from patients [59]. Reliability involves link quality, packet delay and electromagnetic interference (EMI). A study that focused on link quality and packet delay developed real-time publish subscribe (RTPS) middleware functions for healthcare systems to guarantee the real-time delivery of data while maintaining QoS [60]. Decision schemes and multi-attribute decision making (MADM) methods were investigated in [61]. In [62], two new scheduling algorithms were proposed to meet the requirement of QoS in WBANs and to overcome the starvation mode of packets without the highest priority. Another study on architecture handled dynamic behaviour and heterogeneous traffic in WBANs for healthcare systems [63]. A new traffic-sensitive WBAN using non-pre-emptive priority queue discipline was presented in [64]. A MAC protocol was proposed in [65] for prioritising multiple bio signs with various characteristics; delay packets are set in minimal time to ensure the effectiveness of the data. Health monitoring schemes and the sensor structure were simulated in [66]. Meanwhile, [67] presented an infrastructure-based method to improve and manage the quality of telehealth applications and the distribution of Internet traffic through the devices that are connected in a HAN environment. In [68], an adaptive resource allocation and traffic prioritization scheme for improving MAC protocol performance was developed based on the channel condition and patient emergency status. In [69], a compositional probabilistic response-time analysis approach was developed for probabilistic real-time systems in BASNs with fixed priority pre-emptive scheduling. EMI is a key technology for improving mobility and service flexibility for various ehealth applications. A high level of EMI is a result of critical malfunctioning of medical sensors [70]. Reference [70] studied the number of users who are forced to disconnect from the network to maintain an acceptable level of EMI. Reference [71] introduced a priority scheme to enhance an efficient wireless healthcare service system for medical/nonmedical devices. Meanwhile, the ontology-based sensor area focuses on extensible ontology that comprehensively describes wearable sensor platforms comprising mainstream magnetic and inertial measurement units (MIMUs) [59].

Analyses of research in Tier 1 indicate that previous studies attempted to control congestion and avoid network failure between Tiers 1 and 2 to ensure maximum network availability and reliability for delivering services in healthcare systems. A network failure between Tiers 1 and 2 causes a shortage in data transmission in Tier 1. In this context, the measurement of a patient's conditions becomes either inaccurate or lacking. In addition, sensor characteristics may result in partial or complete failure, which can degrade the performance or even destroy the stability of the overall system [72]. No previous study regarded fault-tolerant systems as a solution to sensor/network failures in Tier 1.

Tier 3

A healthcare provider in medical institutes (MIs) generally allows medical professionals to monitor and analyse vital signs in real time and provide patients with appropriate healthcare services. This category contains the server-based domain.

Server based

This domain involves the use of a remote computer for real-time monitoring to enable medical staff to analyse a patient's condition (data) in real time and provide the patient with appropriate services. It can also manage, organise and support professionals in telemedicine. Generally, it comprises a medical institution's server, patient history and database and service generation [9]. The medical centre server side is connected to distributed hospital servers [4–8] to provide healthcare services. Studies in this domain focused on six areas based on the features and contributions offered in telemedicine application: analysis process, environment management, evaluation-based server, security- and privacy-based server, collaboration fields and remote monitoring (tele-monitoring).

The analysis process sheds light on data analysis in telemedicine. Generally, data analytics services can monitor and detect vital signs that can be provided to healthcare providers or physicians [73]. Various studies on the analysis process in the server of telemedicine focused on big data analytics for sensing technology that can contribute and improve the effectiveness and efficiency of healthcare services [73, 74]. Another study focused on activity pattern mining that enables the creation of an activity database by extracting the frequent patterns of smart homes' sensor history [75].

The second area is the management of environment and medical facilities. Healthcare institutions should concentrate on managing health organisation due to many reasons, such as dynamic processes, distributed hospital organisation and long waiting time of patients in ED. Therefore, institutions should review the processes of managing emergency facilities and the implementations of measures to protect the care quality for each consumer [63]. Many studies focused on sensor management and data gathering for healthcare monitoring of elderly people in hospitals [76, 77]. Reference [78] supported physicians in managing their organisation in an efficient manner and anticipating the features of overcrowding. In the evaluation-based server area, [79, 80] evaluated the features and effectiveness of common tele-healthcare systems to establish a ubiquitous, user-friendly and patient-centred system for each patient and their caregivers depending on the continuous application of clinical guidelines. Reference [81] investigated the efficiency of a web-based healthcare system that enables patients to record measurements of blood pressure, body weight and number of steps walked per day.

In the security- and privacy-based server area, [82] focused on medical data generated by medical sensor networks by proposing a mechanism to ensure integrity, confidentiality and fine-grained access to outsourced medical data. Reference [83] focused on the security of the e-Healthcare society by establishing a low-cost and secure (LCS) communication system. The collaboration area focused on the cooperative environment and tele-expertise between professionals. Cooperative environment refers to integrating u-healthcare environments in virtual organisations. In the study of [8] on decentralized data, PHRs can be stored and accessed by distributed data centres with high performance. Meanwhile, [84] focused on empowering healthcare information systems to provide a good level of quality information anywhere and anytime and to produce heterogeneous and distributed resource access solutions that are suitable for user requirements in various contexts. Tele-expertise between professionals in telemedicine allows physicians and/or health caregivers to cooperate by sharing knowledge and expert advice, which are used as explanation elements for medical professionals in their decision-making processes and to support diagnosis and treatment for patients [2, 10, 14, 85, 86].

The area of remote monitoring (tele-monitoring) includes studies on patient prioritization, E-triage server and provision of services. Patient prioritisation refers to prioritisation methods for patients; it puts patients in queue to obtain necessary treatment and transports them to hospitals according to their condition. The condition of each patient is an effective assessment tool for ensuring the prioritisation category based on medical guidelines. Reference [87] focused on remote monitoring for patients and proposed an Android application by using IoT in two stages. Firstly, the application gathers vital signs from each sensor and classifies the patient status. Second, it sends these vital signs over LTE-Femto Cell networks to healthcare centres in order to prioritise patients. Reference [88] developed an efficient optimisation system by using the multi-swarm PSO technique to address issues, such as unavailability of servers for large data storage, difficulties in providing services for a large scale of patients, non-categorisation of data requests and enhancement of prioritisation of patients. The E-triage server means that the triage is located in the on-site rescue control centre for monitoring all vital signs of patients. Triaging involves initially sorting patients who arrive at ED by quickly identifying patients who require immediate healthcare because of life-threatening, urgent conditions [9]. Reference [28] presented a system for monitoring vital signs that uses a photoplethysmograph. It allows health professionals to measure patients' temperature, pulse and respiratory rate in a constant and comfortable manner for patients in emergency rooms, and it supports the triage procedure. A functional wireless pulse oximeter prototype was developed by [89] to measure data gathered from patients. The system outputs a clinical analysis by a central unit, helps coordinate first aid teams and updates the information on clinical status and patient locations. Another study [90] developed a ZigBee sensor network for monitoring patients' pulse condition. The sensor node is placed on the arm of a patient. The system comprises a number of sensor nodes, and a CN gathers the pulse rate from the nodes through a ZigBee wireless and web interface. The patients' pulse rate graph can also displayed.

The service provision area is an important and attractive part of telemedicine monitoring, and it acts for the treatment process of patients. In healthcare, personalisation means understanding the needs of all individuals/users and helping address these needs in a given context. Personalisation mainly consists of two steps: user modelling/profiling and content/service recommendation according to user profile [9]. References [91–96] focused on supporting an alert emergency service generated when the vital signs of a patient become abnormal. The alert is sent to caregivers and emergency medical teams. References [97–100] presented many services to patients, such as telehealth consultation, drug prescription, tips, recommendations and suggestions. Reference [101] introduced a system to enhance emergency treatment and confirmed the necessity of a cloud computing system for emergency rural healthcare to minimise deaths caused by time delays during patient transportation and lack of appropriate and timely first aid. Moreover, [102] provided healthcare services on the fly amongst vehicles that seek healthcare services in the case of traveling. Reference [103] presented first-aid operations, and these services are provided while the patient is in an ambulance. Reference [104] developed a novel telehealth eldercare service that connects a remote physical therapist in a clinic to a senior at home by providing verbal, auditory and visual cues to perform correct exercise movements. The management of the therapy prescribed to patients with visual difficulties amongst simple notifications of drugs and doses was examined in [105].

In conclusion, among the studies in Tier 3, those on environment management facilitated medical health organisations and institutions by helping distributed hospitals provide healthcare services to remote patients. Studies on security and privacy area revealed that threats could pose possible danger and might exploit the vulnerability of a medical server. It could breach security and therefore cause possible harm in these systems, which in turn would stop the services from the medical server side. In addition, the studies in the area of healthcare service provision delivered solutions for continuing these services in cases of medical servers in the normal mode. However, how can we guarantee that these services are continuously provided to patients even in the case of server failure? A fault-tolerant system for ensuring continued healthcare services in this category has not been considered.

Tier 2

In Tier 1, patients can acquire their vital signs through the sensor-based domain and send them to Tier 2 through small area network protocols (Zigbee and Bluetooth) and WBAN [9]. This category includes two domains: gateway based and mHealth doctor.

Gateway based

The gateway in telemedicine architecture is used to bridge sensor-based vital signs to remote stations by using interfaces, such as LAN, 3G, 4G or u-health [106]. The use of gateway devices enables vital signs to be moved from the inter-body area network to the beyond-body area network. These devices, such as PDA, can be employed to create a wireless link between two networks and to transfer, integrate and manage body information for enhancing the coverage range of healthcare systems and applications [107]. This domain is divided into four areas: integration and aggregation, network management, decision support system (DSS), and support to designers.

In the integration and aggregation area, integration is developed with specialized global capabilities, such as system integration, which allow a mobile operator to create solutions connecting healthcare providers to patients as well as to other healthcare players in the industry. Meanwhile, aggregation can increase the scalability and flexibility of mobile aggregation centres. Various studies have been conducted on the integration of multiple heterogeneous sources to enhance the use of data in healthcare systems and clinical decisions. A linear sequential data modelling approach called automatic generation of unified datasets (GUDM) with an expert-centric priority-based scheme was proposed in [108]. Another study [109] proposed a theory-based approach and highlighted the design decisions among technology, architecture and algorithmic solutions. The integration of u-healthcare environments in virtual organisations was applied in [110]. Other studies focused on aggregation data either by proposing a cloud-assisted WBAN-based architecture [111] or by introducing a priority-based health data aggregation (PHDA) scheme with privacy preservation for cloud-assisted WBAN [112]. In the network management area, various studies focused on developing and enhancing mobile healthcare network management. A priority-aware pricing-based capacity sharing scheme that considers the requirements of QoS for multiple gateways was introduced in [113]. Gateways are intelligent and can adopt the priorities of transmission and data rates based on the importance of signals. A study on scheduling transmission in the eHealth network, which is known as an incentive-compatible mechanism that considers delay sensitive medical packets, was proposed in [114] to maximise the profits of the gateway whilst ensuring higher service priorities to more emergent medical packets. Another study [115] improved the mobile healthcare system and network utilization by proposing a multi-user sharing scheme that considers priority and random access with diverse medical information. The area of DSS involves a computer-based system that supports the process of decision making to enhance correct diagnosis of diseases. A model for enhancing the quality of decisions was presented in [116] to enhance the sets of context awareness and processing and to improve the presentation of information to healthcare professionals. Another study [117] introduced a light-weight rule-based reasoning system that is embeddable in mobile devices and can be intentionally optimised and designed to build knowledge-based DSS efficiently. Reference [118] proposed a novel architecture of cyber-physical systems (CPS) for healthcare applications to detect and minimise the false alarms generated by sensors when monitoring vital signs that cross the threshold. In the area of support to designers, context-based and rule-based approaches were built through new techniques for designing adaptable mobile user interface (MUIs) [119]. The aim of [118] was to show the use of decision table techniques as a basis for designing complete and consistent MUI context adaptation rules for mobile applications with one category of users.

mHealth doctor

Mobile health (mHealth) is a general term for the use of mobile phones and other wireless technology and communication devices to educate consumers about preventive healthcare services in medical care [120]. According to [121], it is a component of eHealth. The Global Observatory for eHealth (GOe) defined mHealth as medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices. mHealth comprises the use of and capitalisation on a mobile phone's core utility of voice and SMS as well as highly complex functionalities and applications, such as 4G and 3G systems, GPS, GPRS and Bluetooth [122]. The domain of mHealth Doctor can be divided into four areas.

Ambient assisted living (AAL) AAL enables the tracking and monitoring of patients who live alone or are treated in hospitals with decreasing independence. Reference [123] developed an ubiquitous system for the processing of video and audio for automatic fall detection. Another study [124] designed and implemented a semantic, data-driven, cloud-based, back-end platform by offering information- and knowledge-based services. Activity models of a single human inhabitant in home environments were proposed to simulate daily activities in [125]. Developments in ICTs, such as IoT and CPS, that are highly intelligent and possess prediction capabilities for daily life (home/office) and in hospitals were examined in [126].

Treatment support and disease surveillance The main role of both topics is to observe, predict and minimise the harm caused by outbreaks, epidemics and pandemics and increase knowledge about the factors that contribute to such circumstances. Studies conducted in this area enable patients to manage and monitor their chronic diseases, blood pressure, body temperature and heart rate to obtain services from the server side as a response. Mobile machine learning model for monitoring cardiovascular disease (M4CVD) was introduced in [127]. M4CVD uses sensors to collect vital signs contextualised with data monitored live from a clinical database to facilitate the monitoring of cardiovascular diseases (CVD). Reference [128] developed a monitoring system dependent on the new Arduino mega microsystem device that uses blood pressure, body temperature and heart rate by implementing algorithms to analyse real-time signals, fuse multi-sensory data and transmit these signals by an Xbee module (radio frequency). Other studies presented applications that can adapt to other diseases, such as diabetes. For example, [129] developed MobiPatterns, a mobile monitoring application that provides continuous monitoring of patients with diabetes via mobile phones and biometric devices; it generates individual patient profiles, education modules and self-control. [130] produced a diabetic mobile application that can provide a patient with proper services. The application depends on low level invasive impact technology via new process models meant to integrate software components and share information. Reference [131] presented a Jeev software application for tracking the vaccination coverage of children in rural communities. Reference [132] developed a social media system known as Mo-Buzz for preventing dengue in Sri Lanka and southeast Asian regions. The system is available on smart mobile phone platforms and a website. A treatment mechanism to support major depression was presented in [133]. It uses the process of decision making to provide personalised and adaptive daily interactive sessions dependent on history data, clinical requirements and current response from patients. Reference [134] proposed a home-based monitoring system for multiple occurrences of FoG and early fall determination for patients with Parkinson's disease by using wireless sensors in the vicinity of the patients. A new coaching approach known as personal coaching systems (PCSs) was developed in [135]. PCSs use body sensors and are integrated with smart reasoning and context-aware feedback to assist patients in maintaining and developing a healthy behaviour. Another study [136] presented a software prototype for the treatment of eating disorders. The prototype can acquire abdominal morphological parameters by using a consumer electronic depth sensor and a Microsoft Kinect-like peripheral component. Reference [5] presented a general approach for building a data-driven platform for urgent DSS to support ambulance and emergency medical service management for patients with acute coronary syndrome (ACS) as a working example. The approach involves the integration of distributed streaming data sources and data storages (containing ECG, EMR, real-time monitoring of medical facilities and schedules of hospitals within a network). Monitoring of patients with mental disorders and cognitive degenerative conditions on the Alzheimer spectrum in a smart psychiatric ICU and in the community was achieved by using IoT in [137].

Triage over mHealth The term 'triage' comes from the French word 'trier' which means 'to sort'. The concept was used in warfare systems to prioritise all casualties and give urgent care to the most critically injured. Studies on triage in mHealth are classified into two directions according to the triage environment. These two are triage-based disaster casualties and Incidents and triage-based home monitoring.

- Triage-based Disaster Casualties and Incidents

In an MCI, the first triage of all injured individuals is essential in the processes of the medical team. Due to the challenges in the accident area, the medical team should implement correct and advisable steps when encountering casualties in the field, and this usually causes inefficient treatments of casualties or misleading information forwarded to the executive emergency physician (EEP) [138]. Reference [139] developed a low-cost and lightweight wearable E-triage with a sensory system and Android-based mobile application for monitoring the vital signs of casualties and transferring these signs to a medical record server in hospitals for clustering into three levels (major, delayed and minor). The device was built from sensors, such as pulse-oximetry and thermocouple breath sensors, RF units and a low-power 8-bit microcontroller unit. The AUDIME project approach was presented in the study of [138], and it is dependent on a hands-free approach for wearable devices or mobile and can evaluate the social acceptance and usability of smart and wearable devices in the context of MCI management. Another study [140] proposed an automatic and intelligent self-tagging methodology for patients in an MCI. It is dependent on critical conditions and consists of three approaches (fuzzy logic-based tagging, aggregation based and table). This study used body sensor networks (mental status, heart rates and respiratory rates). Wearers in [141] presented a solution to enhance the management of MCIs through the combination of a mobile device and a sensor-based platform and by adopting the START method. The decision criteria applied were walking capabilities, respiratory rate and circulation conditions. Reference [142] proposed a platform of a body-worn vital sign monitor that can acquire body temperature, SpO2, ECG and multichannel auscultation for developing a field accident and emergency Centre intelligent monitoring system to enhance medical resource allocation in disaster environments. A system to assist patients in real time was developed in [143] by using mobile E-triage accomplished via crowdsourced and sensory-detected information and by adopting machine learning techniques. A diorama-based system was introduced in [144]. The system can provide awareness for search and rescue operations in urban environments in outdoor and indoor settings and for triaging patients with active RFID tags to mark the locations of trapped patients and points of interest. The Ripple Project in [145] involved the creation of an MBAN of sensor-based to the triaging process in a disaster scenario. This study prototyped a system that integrated 802.15.4 system on chip (SoC), ARM 7, temperature probe, electrocardiogram and pulse-ximeter.

- Triage-based Home Monitoring

Reference [9] introduced a framework called multi-source healthcare architecture (MSHA) for developing telemonitoring systems among integration multi-sources (ECG, SpO2 and BP) and text inputs. The study attempted to improve healthcare scalability efficiency by supporting remote triage and prioritising patients with heart chronic diseases. The framework can provide healthcare services by using the data fusion method.

Network failure between tiers 2 and 3 The studies in this section focused on tracking and interacting with users or patients by using mHealth when a network connection failure occurs between Tiers 2 and 3 (lost communication links with the medical server side).

Reference [146] presented a prototype of WPAN technology to track pilgrims in case of disasters and enable communication even in tower-less areas by using the ZigBee method. The system included two modules. The first one is surveillance-side control, and the second one is person-side that contains multi-colour LED and heart beat sensors. Another study [147] considered an mHealth system used in tsunami-stricken disaster scenario to accommodate the processes of disaster recovery in environments without functional telecommunication services and smartphone systems to connect with nearby users. Vital signs are collected then transmitted over D2D and LTE-direct technologies by establishing infrastructure-less mobile/wireless ad hoc networks to restore the lost communication links. Another study [148] investigated an approach to address the challenges of improving communication reliabilities in patient monitoring. This study proposed (1) power management protocols and a (2) framework that models the complex decision logic involved in leveraging mobile ad-hoc networks for diverse patient monitoring scenarios. Meanwhile, a temporary (ad hoc) wireless network was presented in [149] for technical feasibility of medical alarm dissemination in an urban environment by mobile devices to the closest hospital or by medical field personnel in the case of congestion or failure of infrastructure-based communication networks.

As mentioned in Section "mHealth Doctor", all studies in these areas presented various healthcare systems and applications through mHealth, which are completely controlled from the server side. A few studies in Section "mHealth Doctor".4 presented a restricted solution in the case of breakdown or interruption of communication between Tiers 2 and 3 by adopting an ad hoc network, such as disaster recovery process or feasibility of medical alarm dissemination to the closest hospital. However, although these studies accommodated recovery processes in environments without functional telecommunication services by using ad hoc networks, they did not seek to replace the infrastructure-based wireless network(s); they merely proposed to supplement the coverage of the infrastructure-based wireless network(s) by a mobile ad hoc network when the coverage from the former is low or non-existent [148]. Therefore, modern healthcare systems that adopt ad hoc networks have established several critical requirements and challenges, such as reliability and timely access to diagnostic information without failure, compared with traditional wireless networks [150].

According to the studies in Section "Server Based", scalability challenges place a substantial burden on telemedicine applications by increasing demands for healthcare services, which causes network congestion and server failures [4, 9, 151, 152]. Unavoidable network congestion causes increased demand on user queries and causes either network failure between Tiers 2 and 3 or failure on the server side [9, 153, 154]. Telemedicine services are dependent on client server architecture [7, 9], and many factors make affect network congestion and server cascaded failure. These factors include loading or denial of service, which causes an interruption in the provision of healthcare services to patients in real time [150, 155–157].

In conclusion, none of the studies in literature considered a fault-tolerant system when various failures occurred in the telemedicine architecture to ensure continuous services through mHealth. Studies that investigated service delivery through mHealth still experience challenges in cases of network failure at Tier 3 [9] or medical centre failures (Tier 3) [4, 158]. Any disruption to a system of the telemedicine architecture can cause link outage, which potentially leads to severe consequences [4, 159–161], such as (i) sensor failure or network failure between Tiers 1 and 2 and (ii) medical centre failure (Tier 3) or network failure between Tiers 2 and 3. The concept of delivering healthcare services in accordance the abovementioned problems has still not been issued yet. mHealth can address these failures to ensure continuous provision of healthcare services to patients for all systems within the telemedicine architecture.

References [3, 4] posited that mHealth can solve the problems mentioned above and can provide services to patients even in cases of network or server failures. In addition, [9], which is considered the most reliable study in this area, presented an architecture known as MSHA that is composed of three tiers and conducted patient triage in (Tier 2). However, this study did not investigate the provision of real healthcare services from hospitals even when services are cut off. The study only presented tips for patients in the case of only one type of failure, which is network failure between Tiers 2 and 3. Many other drawbacks are observed in this study, as explained in Section "Triage Standards and Guidelines". Moreover, [9] identified chronic heart disease as a case study. Chronic heart disease in a remote monitoring environment was used as a case study in this research for the proof of the concept.

Healthcare service challenges in telemedicine application

According to [162], many challenges exist in healthcare service provision. However, the scope of this study is related to the scalability and network congestion on the server side that causes server and network failures. The framework of this section focuses on reviewing scalability and network congestion challenges, which are explained in Fig. 4 (in yellow). Scalability is a challenge in providing healthcare services in disaster scenes, aging populations (i.e. increased demand for healthcare services and online doctor visits) and network congestion [9, 151, 152]. It causes another problem in healthcare services, that is, loading on the server side resulting in server or network failure. These challenges acquire increased significance when patients are far from hospitals and use healthcare services (telemedicine system) that are interchangeable even with network congestion.

This section discusses healthcare scalability and network congestion problems and server failure challenges. It also identifies how research can respond innovatively and contribute to the realisation of efficient and effective healthcare service provision systems.

Healthcare scalability challenges

Increasing healthcare service demands have led to the urgent need for effective and scalable healthcare services [3, 151, 152]. Studies have attempted to improve healthcare services in telemedicine and solve scalability problems, disaster scenes, mass casualties and network congestion. This section introduces related research on the dilemma of the increasing number of patients requiring timely and effective telemedicine services. As explained in Fig. 5, an increase in the number of users is expected to occur in three aspects, as listed below.

Aging population As the numbers of the aging population and chronic diseases increase, our society becomes more health-aware, and patients become health consumers seeking for better health management. People's awareness is shifting towards patient-centred health services rather than the traditional hospital-centred health services, which has propelled the evolution of telemedicine research from the classic eHealth to mHealth. The combination of WBAN and mobile and ubiquitous telemedicine has a great potential in promoting the provision of next-generation uHealth [106].

According to the continuously increasing numbers of patients, the aging population is the main problem in healthcare services [163–165]. The existing limited set of healthcare physicians should efficiently use any developed system to absorb such a growing system demand [166]. The Center for Medicare and Medicaid Services (CMS) [167] states that U.S. healthcare spending in 1970 was approximately $75 billion, or $356 per resident, and accounted for 7.2% of the gross domestic product (GDP). Moreover, CMS studies show that healthcare spending will be more than $4.3 trillion by 2018, or $13,100 per resident, and account for 20.3% of the GDP, as shown in Fig. 6.

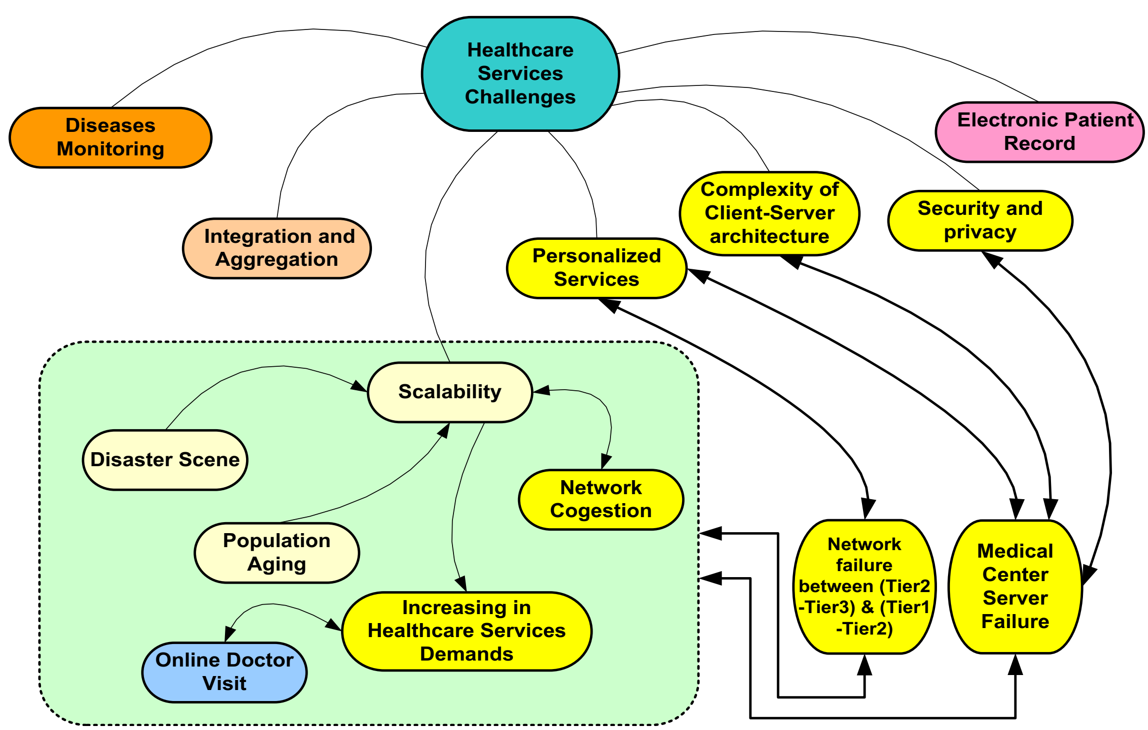

Fig. 4 Taxonomy of healthcare challenges and scalability problems

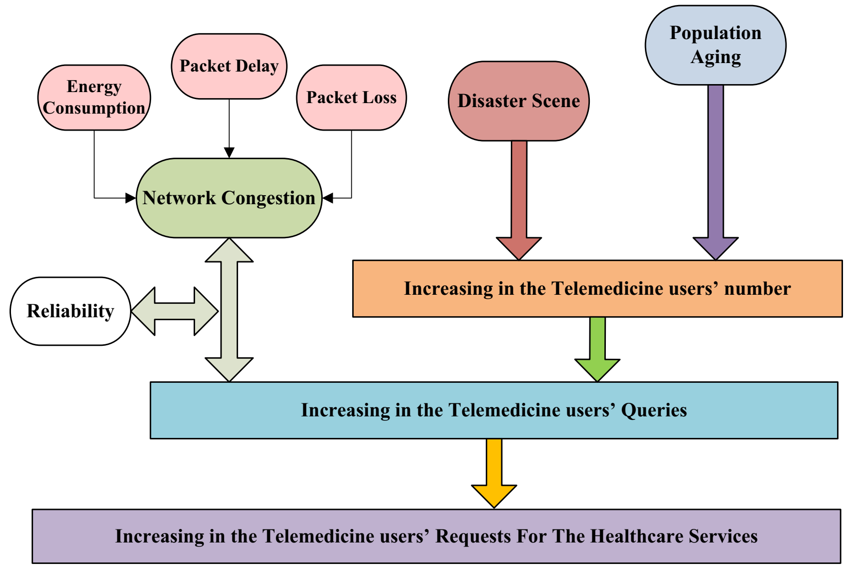

Fig. 5 Problems that cause an increase in users' requests in remote healthcare monitoring systems

According to analyses in literature, researchers have begun to examine how to promote healthcare service provision systems in response to the aging population challenge. This section reviews several relevant studies that improved telemonitoring systems for older people.

The main goal of [125] was to assist the development and testing of algorithms required in AAL projects through the proposed daily activity simulator. The designed simulator runs at multiple abstraction levels and can connect distant caretakers and relatives far from the places where the patients live by using the Internet. Reference [168] developed a monitoring system for elderly patients and proposed a method that can recognise heartbeats accurately. The novel system proposed by [163] supports the categorising of elderly patients who arrive in the emergency room for medical assistance whilst reducing unnecessary admissions. In [97], a framework that addresses the scalability issue was proposed. The framework comprises a WBSN, a service-oriented architecture (SOA) and web services and offers health services for patients, caregivers and doctors. However, studies that investigated aging population problems showed an increased demand for delivering services to elderly people, which causes scalability challenges by increasing the number of queries on the server side (medical centre).

Disaster scenes and MCIs Many people are injured in disasters annually, and providing adequate medical services to the injured remains a challenge [3, 169]. Healthcare service delivery

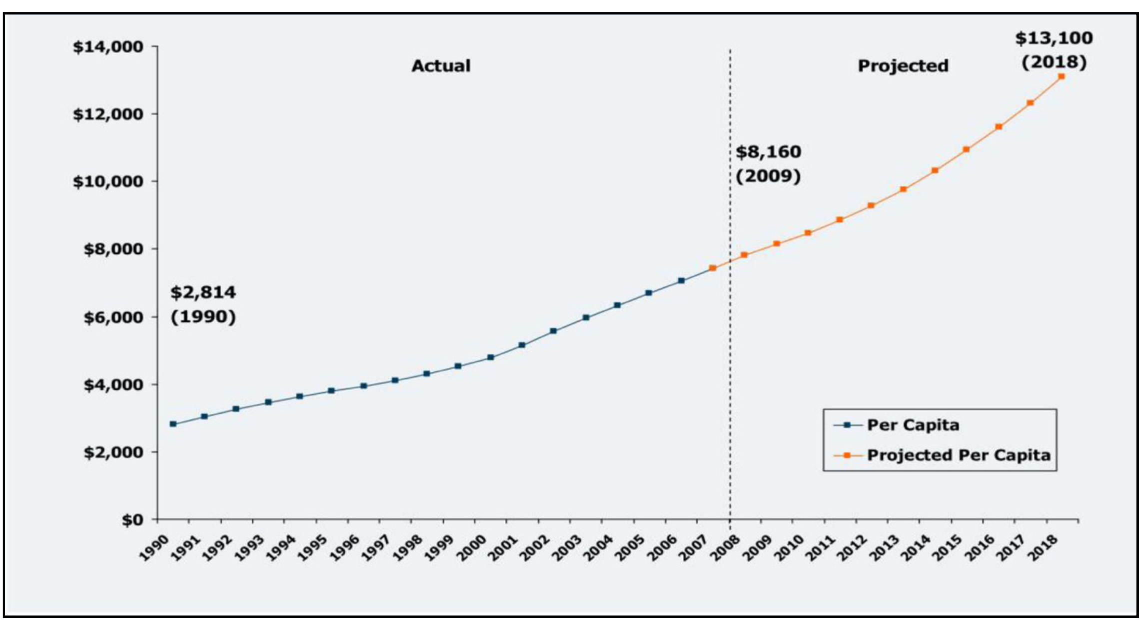

Fig. 6 United States national healthcare expenditures per capital [167]

during disasters is more complex than routine healthcare in several ways. According to [170], to protect the health of the population during and after disasters, essential emergency services must be provided through a multi-sectoral (involving more than one sector) effort to ensure the continuity of healthcare services. These services can be delivered to the casualties during healthcare network failure. When the number of critically injured patients is large, those who are dead or expected to die should not be offered attempted resuscitation. A healthcare system was developed to monitor pulse rate and Spo_2 in [171] and pulse rate and ECG in [172]; both systems can be used to transmit vital signs of causalities to a medical centre server. On the server side, a rescue commander can monitor casualties in real time. However, casualties cannot transmit their vital signs to the server when communication fails. A novel queuing network that models the victims' health status in the aftermath of a disaster was proposed in [173]. The study focused on model development rather than problem solving. Two studies focused on mobile ad-hoc networks (MANETs) in their work. Reference [174] developed a triage system that depends on mobile agents' MANET. However, this approach was utilized in the worst-case scenario where only small handheld devices carried by the emergency personnel are available. It also integrates well when synchronous connections are possible, such as when a mesh network can be adopted. Reference [175] presented a new technique to rank the emergency level of mass casualties by a localized ad-hoc sensor network and localized real-time sensor data processing and proposed to push the limits of connected medicine by enabling patient-to-patient (Pa 2 Pa) communication in mass casualty scenarios.

Although ad-hoc-based architectures provide fast deployment when encountering dynamic environments, such as medical emergency care response or in disaster sites [176], efficient QoS provisioning for MANETs is a challenging task, especially for various types of traffic according to [177]. As mentioned previously, the main range of disaster problems includes massive destruction of buildings (including the server side), transportation networks and utility delivery systems [178]. However, when the number of patients requiring care reaches thousands as in the case in natural disasters, a number of people need to seek medical care centres temporarily [179]. In this scenario, temporary queries can cause significant disruptions and loading on the server side. Hence, the concept of delivering healthcare services according to the challenges above still entails issues.

Network congestion Congestion exerts negative impacts on the overall network performance, such as increased end-to-end delay, packet loss and wasted power consumption, because of the large number of re-transmissions [54, 55, 57], as shown in Fig. 5. Network congestion can reduce QoS when network nodes carry more data than they can handle. Different applications in telemedicine environments, such as medical record retrieval, real-time monitoring and treatment that supports diagnosis, have different levels of tolerance to service quality and delay [180]. However, modern healthcare systems face additional critical challenges, such as reliability issues and timely access to diagnostic information without failure [150]. Furthermore, challenges in congestion control and reliability arise because of the incorporation into sensor networks along with open research issues in healthcare services [80, 181]. Congestion is one of the most serious phenomena that affect the reliability of information transmission in any network [150], and it causes server failure [153, 154]. In critical life applications that involve large numbers of patients, congestion is undesirable and may cause death [58]. In medical emergency applications, sensors attached on patients transmit vital signs simultaneously and frequently, and this scenario may result in network congestion. Therefore, many studies proposed a healthcare traffic control scheme over modern heterogeneous wireless networks to prevent congestion and guarantee QoS regarding service responsiveness and reliability. A proportional and fair allocation control strategy for healthcare terminals, such as devices or routers, was introduced in [150]. This strategy regulates the rate of data flow and makes it proportional to the information priorities. A differentiated scheduling and traffic scheme for WBAN that is dependent on the classification and prioritisation of patients' data was proposed in [182]. The drawbacks of this scheme include the definition of services as the number of departing packets from the queue in CO per second, thus indicating that the study is not relevant to the provision of healthcare services. Reference [56] proposed a congestion control protocol that is fuzzy-based for WBAN applications that can monitor ECG signals remotely. Reference [57] proposed a priority-based congestion avoidance scheme called PCAH to avoid congestion and provide an efficient mechanism to save energy. A data-centric congestion management protocol known as HOCA using AQM was also proposed for healthcare applications to avoid congestion in the first step (routing phase) by using QoS-aware routing in multiple paths [58]. However, issues related to determining the sensitivity of sensing packets are yet to be addressed.

Scalability is also related to the connection between a WSN and the Internet; thus, telemedicine systems are subject to a large amount of queries [183], and congestion and loading occur on the server side [9, 184]. Network congestion causes either network [3, 9] or server failure [3, 140, [154]. Furthermore, telemedicine services are dependent on client-server architecture [7, 9], so any disruption to telemedicine networks and the server side can cause link outage, which potentially leads to severe consequences [159–161]. Failure in telemedicine architecture has many causes. On the server side (medical centre), the cost of failed online transactions can be significant in telemedicine applications, which causes unavailable services for patients. The common failures observed on the server side are illustrated in the next section.

Server failure challenges

Client/server availability is a complex issue because of many possible configurations of client/server environments and failure modes of client, server and network devices [155, 156, 185]. Such complexity makes it difficult to properly account for availability in client/server architectural design [3, 169]. Generally, server failures cause difficult implementation of services in large-scale distributed applications, which are typically highly dynamic. By definition, they are loosely coupled and often unstable because of the unreliability of servers. Services used in applications can be interrupted [186], deleted, moved and subjected to different sources of failures or simply become unreachable because of communication faults [187]. This situation is natural in server failure modes [188, 189]. In distributed client/server environments, unavailability should be defined in terms of system failure and measured in terms of system uptime or downtime because it is difficult to define system failures [156, 190]. The common classification of server failures and outage data according to [153, 156, 184, 191, 192] are listed in Table 1.

In many cases, the real cause of failures is never diagnosed (the operators merely determine how to get the users back on line), which means that such failures could recur [155, 156, 185]. These issues differ from study to study. Many studies addressed other challenges, such as database, application failures, human errors and security violations (e.g. denial of service or DOS attacks) [122, 184, 188, 193]. Meanwhile, other studies addressed various system failures, including single and multiple system failures [189]. Although the availability of the cloud is an essential quality, many studies showed that the failure rate and response time are not exponential, and the probability distribution for high availability cannot be achieved in a closed form [189, 194]. In this context, utilising cloud storage providers has become common practice for end clients. However, existing cloud storage suppliers do not offer any sureties on haul availability and protection [189, 194].

In conclusion, several failures, such as server loading, disaster scenes, network congestion and DOS, can have disastrous effects on healthcare services. Server failures in this context can result in high costs in telemedicine application either in the form of lost opportunities or penalties for failing to meet service level agreements [3, 159–161].

Remote healthcare monitoring over telemedicine

Remote monitoring was defined by the Heart Rhythm Society as '*the automated transmission of data based on pre-alert related to device functionality, clinical events and clinical condition of patients*' [195]. Remote monitoring transmits in real time patients' vital data to clinicians through the use of advanced technology [196]. Remote monitoring in healthcare offers a great promise because it is easy to use for elderly, frail and housebound patients [197]. Several remote monitoring strategies that involve telephone interviews, IoT-based technologies or other sophisticated systems have been presented [198]. An example is electronically transferring vital signs through remote access control via implantable, wearable or external hemodynamic implantable devices [181]. The personal health monitoring devices introduced by the 'Telemedicine 2.0′ era are now part of the disease management system. A common disease management system augments the functions of data collection and sensing of previous-generation devices with an array of online services. These services involve data visualisation, data aggregation and analysis functions for patients' personal physicians along with alert functions that can inform caregivers of urgent conditions noticed in a patient's telemetry. This architecture of the

Table 1 Common classification of server failures and outage data

Failures Types	Explanations and Examples
Physical faults of a hardware component such as CPU or power supply	Examples include a failed Ethernet card in a hub and a broadcast storm on a LAN caused by a bad supervisor card.
Design errors in both hardware and software	Including application software failures. For example, an out-of sync condition between file-server and line-handler processes following a host-application failure. In another case, a broadcast storm on an internet LAN due to a packet that made the LAN bridges loop.
Operations errors	Caused by operations personnel or users due to accidents, inexperience, poor procedures or malice. For example, after power was restored, an Ethernet card (to a file server) didn't properly restore because it had been incorrectly configured.
Environmental problems	Such as power or cooling system failures, failure of external network connections (such as a leased-line outage and congestion), natural disasters (earthquake, flood), accidents, or terrorism.
Reconfiguration (planned) outages	Including maintenance and configuration changes.
Service Unavailable	The server was unable to handle the HITP request due to a temporary overloading of the server.

'Telemedicine 2.0′ system has three tiers [199], as illustrated previously.

RHMS in telemedicine is '*an attractive, important, and rich research area because it relates to human healthcare. Improvements in this system can be made through different scopes, such as introducing new hardware (sensor devices) and designing new software and algorithms that can improve the monitoring process and efficiently handle the data to improve medical decisions and services*' [200]. Telemedicine can ensure the continuity of care in chronic diseases. Remote monitoring, in particular, is effective for managing chronic diseases for the elderly, aside from reducing mortality rates and hospitalisation [9, 201, 202]. Furthermore, many clinical benefits are related to remote monitoring of chronic patients [203, 204]. The chronic diseases in remote healthcare monitoring are demonstrated as a case study in the next section.

Chronic diseases in remote healthcare monitoring

Chronic diseases have become an increasingly important issue in e-healthcare systems worldwide [205]. For example, the clinical expenses for chronic diseases in the United States are projected to reach 80% of the overall healthcare expenses, and more than 150 million people would experience chronic conditions by 2020 [206]. Chronic disease adds considerable burdens on individuals and health systems because of frequent unscheduled visits to emergency departments and lengthy hospital admissions [151, 207]. Unless efficient and cost-effective interventions are implemeneted, chronic disease rates will continue to increase in developing countries [208, 209]. Currently, the surge in elderly and chronically ill people in the society requires continuous health monitoring [210]. This increasing burdens and medical cost crisis influence healthcare service providers, researchers and policy makers as they provide remote healthcare to individuals suffering from such diseases [106, 210]. However, physiological data monitoring alone achieves little [211]. Proper intervention must be applied because the monitoring person should keep observing changes in the vital signs and other measurements of many patients; the monitoring process should be implemented around the clock (24/7) to provide sufficient emergency support [212]. Moreover, reductions in hospitalisation and mortality have been reported for home telemonitoring with devices [212–214].

Homecare is a vital and efficient means of managing chronic illnesses [215]. The need for home management of patients using telemedicine is increasing [216]. A common and efficacious approach that can ensure care continuity, especially in chronic diseases, is highly needed [200]. New technologies have increased the abilities of home care providers because numerous chronic diseases that used to be treated in hospitals only are currently being managed in the home safely [217].

One of these technological advancements for the elderly is wearable devices. References [218, 219] revealed the positive attitudes of users towards the application of wearable devices in healthcare. The benefits of wearable devices in healthcare have been widely studied. By conducting a discrete event simulation, [52] found that healthcare wearable devices yield beneficial results in reducing patient denials and serving many patients. In addition, healthcare wearable devices provide doctors with improved abilities to monitor and supervise their patients' wellness [220].

Remote patients, '*those who live far from hospitals and use telemedicine, may suffer from different chronic conditions, such as chronic heart disease, diabetes and chronic blood pressure*' [206, 221]. However, heart disease was selected as a case study in this research because it is the leading cause of death worldwide. Furthermore, it has been adopted by most relevant studies in this area.

Heart disease

The World Health Organization reported that approximately 12 million deaths occur worldwide yearly because of heart disease [222]. Chronic heart disease includes several types, the symptoms of which can be manifested in patients. For example, cardiac arrhythmia is a life-threatening medical emergency that might lead to cardiac arrest and sudden death. According to the American Heart Association (2010), because of arrhythmia, about 55% of patients with heart disease die [206]. Dangerous situations of arrhythmia, such as fibrillation or ventricular tachycardia, are common results of vortex-like re-entrant electric waves in the cardiac tissue. Automatic diagnosis of heart disease is a vital, real-life medical concern because heart disease affects patients' health and working performance, particularly among the elderly [222]. Telemedicine is a vital part of a strategy for the delivery of efficient patient healthcare with many branches of cardiology disease [223].

Many studies have been conducted on the use remote monitoring for the management of cardiac diseases and cardiac home cures, and these studies demonstrated its suitability in terms of cost savings for the same health outcomes [181]. Telemedicine methods exert valuable effects on chronic heart failure care [212]. Mortality and hospitalisation reduction have been reported in home telemonitoring [212–214]. In addition, vital signs, such as ECG and SpO2, are highly important in triaging because they provide an objective complement to the triage decision and optimise inter-rater consistency [224]. Chronic diseases are long-term diseases and require the classification of patients' diagnostic information through triaging. Additional explanation about the chronic disease sources used to measure patients' medical vital signs is provided in the next section.

Sources used to measure patients' medical vital signs

Measuring patients' vital signs can be performed with various medical devices. Vital signs are useful in monitoring and detecting medical problems and can be measured in medical units, at homes or elsewhere [225]. Medical sensors are vital in telemedicine and remote healthcare monitoring. Continuous health monitoring requires system sensors to be active around the clock [162]. According to literature, various types of sensors are adopted in telemedicine application for patients [80, 129, 226]. Several studies, such as [106, 227], used different sensors to measure different diseases. According to [228], there is a persuasive demand for the integration and exploitation of heterogeneous biomedical information to improve clinical practice, medical research and point of care. Reference [229] showed variations in the vital signs and chief complaints applied in triage scales. For example, MTS and eCTAS include the chief complaints leading to ED visits, but no study has analysed which of the chief complaints are important predictors of mortality after triage. The number and type of sources depend on the type of the disease that the patient needs to monitor. References [4, 9] identified and validated four medical sources related to chronic heart diseases: three sensors as signal sources and one as a text source. Applying a group of heterogeneous sources related to heart chronic diseases in one healthcare platform is important in healthcare monitoring [4, 9, 228]. As a result, the sources and features involved in [4, 9] can be used to monitor patients with heart chronic diseases. The description of the four relevant medical sources used to triage chronic heart disease patients are shown in Fig. 7.

As shown in Fig. 7, different sources, sensors and text (heterogeneous sources) need to be involved in this research. These sources demonstrate the diagnosis and reflect the medical signs and symptoms of patients. They show the important demands of using multiple sources for remote monitoring of chronic heart disease in telemedicine to identify the triage level. Text data (complaints) can be used as a medical source to improve services and triaging accuracy. ECG, SPO2 and BP sensors need to be employed in this research as well. According to [4, 9], non-sensory data are important in RHMS. The relation between complaints and vital signs are operationalised as the changing relative importance of vital signs [233]. Accordingly, different sources (heterogeneous data), sensors and text need to be involved in this research. Previous studies that involved heart disease monitoring used a combination of these sources to obtain the triage level of the patient [4, 9]. Thus, mHealth that aims to provide healthcare service to patients needs a process that identifies the triage level of patients by adopting the mentioned sensors.

Triage standards and guidelines

Different triage systems, standards and guidelines were reviewed in the studies presented in Table 2.

Although paper triage tags are widely used, they have many limitations [169], such as lack of real-time monitoring, triaging by officers only, triage for patients who are using telemedicine and are far from triage officers, EDs are not addressed and difficulty in collecting physiological conditions. Therefore, the trend has shifted towards digitalisation of the triage system, such as MSHA and eMEWS [9]. According to [9], digitalisation of the triage has become a

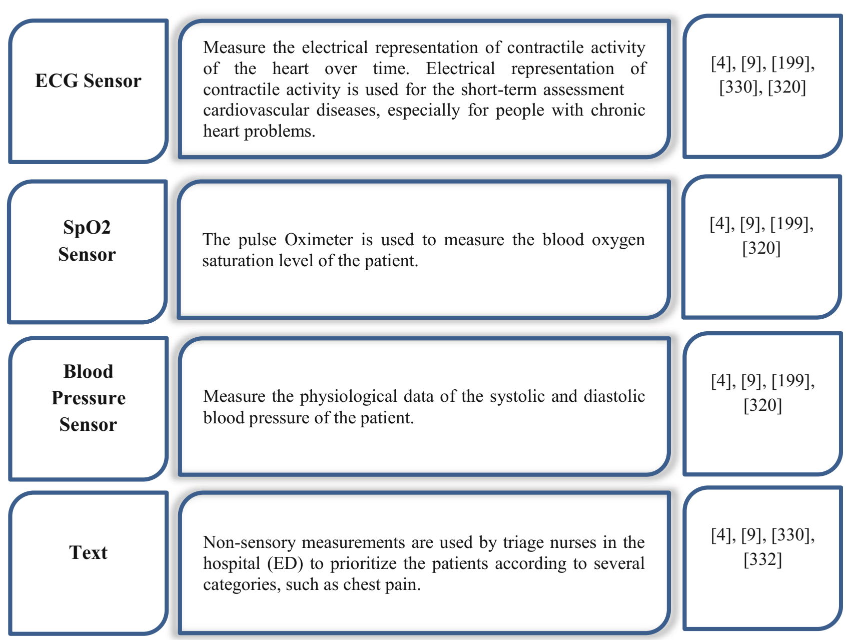

Fig. 7 Medical sources used in monitoring patients

Table 2 State-of-the-art triaging systems

Triage System	Description	Triage performer	Domain	Type	Number of categories and their name
Early Warning Scorecard (EWS) [234]	Simple scoring system for bedside monitoring to serve as a clinical add-on using routinely collected vital sign data	No specifications	Traditional	Paper-based	Yellow Orange Red Blue
Australian triage scales (ATS) [235]	Designed for use for emergency service of hospitals based in Australia and New Zealand; it is a scale for scoring clinical urgency	Triage nurse	Traditional	Paper-based	Not urgent Less urgent Urgent Very urgent Immediate
(CTAS) [236]	Used by all Canadian EDs. The system mandates that every patient presented for care must be at least visually assessed within 10 min of presentation. Assigns acuity based on the chief complaint and a focused subjective and objective assessment	Physician /Nurse	Traditional	Paper-based	Immediate Very urgent Urgent Standard Not urgent
Modified Early Warning Scorecard (MEWS) [237]	MEWS is a modified version of EWS. Vital sign data are manually sampled and recorded	Medical staff	Traditional	Paper-based	Low Medium High
Electronic Modified Early Warning Scorecard (eMEWS) [237]	eMEWS represents a shift from paper-based warning scorecard (eMEWS) systems to electronic systems. eMEWS is often designed and developed around paper-based MEWS guidelines and associated protocols	Medical staff	Traditional	Digital	Not specified
(METTS) [238]	Developed at Sahlgrenska University Hospital and has been used in ED since January 2005	Physician /Nurse	Traditional	Paper-Based	Red Orange Yellow Green Blue
Emergency Severity Index (ESI) [163]	Designed for use in the ED triage by the US Department of Health & Human Services	Triage nurse	Traditional	Paper-based	Immediate Emergent Urgent Semi urgent Not urgent
Manchester triage system (MTS) [239]	Developed in 1994 by a group of professionals specializing in triage. Classifies risks into five categories	Physician /Nurse	Traditional	Paper-based	Immediate Very urgent Urgent Standard Not urgent
Bispebjerg Early Warning Score (BEWS) [240]	Used by triage nurses inside ED to identify severely injured and/or critically ill patients who must be received by an emergency or trauma call (TC)	Medical staff	Traditional	Paper-based	Not specified
(START) [169, 241, 242]	It is broadly used because it sorts casualties into four categories without medical equipment. Used in disasters	Triage officers	Mass Causality Incidence	Paper-based	Immediate Delayed Minor Deceased
Jump START [242]	Developed for paediatric patients 1–8 years old. Designed to parallel the structure of the START triage system	Triage officers	Mass Causality Incidence	Paper-based	Deceased-black Minor-green Delayed-yellow Immediate-red
Paediatric Triage Tape (PTT) [243]	Relates the child's length to age-related changes in normal physiological values. The information is presented on a waterproof tape and can be used in conjunction with any existing triage label system	Medical staff	Mass Causality Incidence	Paper-based	Immediate: red Urgent: yellow Delayed: green Dead
(STM) [242]		Medical staff		Paper-based	

Table 2 (continued)

Triage System	Description	Triage performer	Domain	Type	Number of categories and their name
	Evidence-based outcome-driven triage and resource management system that maximises expected survivors in consideration of the timing, availability and capability of transport and treatment resources		Mass Causality Incidence		Group three/slow Group two/ moderate Group one/ high rate of deterioration
Military Triage [244]	Classic military triage is based on a series of guidelines known as the conventional North American Treaty Organization triage classification	Not specified	Mass Causality Incidence	Paper-based	Immediate Delayed Minor Expectant
MSHA algorithm [9]	Algorithm triage to generate a PC value that classifies users according to the severity of their emergency cases	Algorithm-based guideline to generate PC value	Remotely	Digital	Red Orange Yellow Blue Green

necessity to provide personalisation services based on the severity of the triage level. According to the research analyses, the MSHA algorithm is the most reliable E-triage system compared with other standards. Table 3 shows the stages and specific performance of the MSHA algorithm and the required specifications that should be adopted in our research.

Table 3 presents a general description and technical review of the performance and contribution of the MSHA framework. According to the scope of our research, many drawbacks are found in MSHA which cannot be fully adopted in the present study. The main drawbacks of the MSHA system are as follows. Firstly, it uses the transmission control protocol/Internet

Table 3 Evaluation of the performance of the MSHA remote triage

Stages and specifications	MSHA algorithm	Our research requirements
System framework requirement	Composed of three tiers (Tier 1, Tier 2 and Tier 3)	Composed of two tiers (Tier 1 and Tier 2)
Number of algorithm stages	Three	Four: another stage should be added for the alarm of sensor-based failures
Algorithm process	Triage and priority	Triage
Output	Three outputs (triage level, priority code (PC) and tips)	Four output (triage level, triage code (TC), healthcare service packages and alarm)
Number of categorized triage levels	Five triage levels	Three triage levels
Number of rules	10: by using fuzzy c-means FCM method	Eight: by using (if-then statements)
Number of healthcare service packages	Five	Three
Type of healthcare services	Provide tips	Provide real healthcare services from hospitals
Output services	1. Services can be provided from hospitals: (surgery Room, surgery team, surgery doctor, O_2 supplier, ambulance, medications, emergency room, doctor, consultant section). 2. Services cannot provided from hospitals: (advice for medication, reminder (alert))	Only need to provide real healthcare services from hospitals (need to exclude services that cannot be provided from hospitals)
Network environment	Wireless communication or mobile cellular networks	With and without wireless communication
Method	Combined evidence theory method and fuzzy logic (fuzzy c-means FCM)	Integrated between evidence theory method and if-then statement (to reduce time consumption and enhance energy efficiency)

protocol socket as the client/server communication model between the patient and unique server. Meanwhile, the scope of the presented research is to exclude the sever side in Tier 3 (medical centre server) and connect with distributed hospital servers. Secondly, the process of this system depends on triage and priority in three tiers, and the priority is dependent on first come first serve (FCFS), which is a problem in healthcare services according to [4]. Thirdly, combining the evidence theory method and fuzzy logic (fuzzy c-means FCM) is not necessary in the MSHA algorithm. According to [245, 246], the theoretical process of fuzzy logic reasoning systems is that the notions of truth and falsehood are considered in a graded manner, whereas the process of using fuzzy c-means in MSHA considers classical logic conclusions that are either true or false. Thus, the present research re-adopts the triage process only and re-qualifies the MSHA algorithm according to the requirement of our triage scope. The priority adopted from the server side is excluded in this study. Accordingly, a new triage algorithm needs to be developed.

Time of arrival of patients at the hospital and healthcare service packages

In this section, the importance and advantages of time of arrival of patients at the hospital and healthcare service packages in telemedicine are described in detail.

Time of arrival of patients at the hospital (TAH)

TAH is an important factor in choosing appropriate hospitals [247–249], especially in this research on chronic heart diseases. Many studies examined the potential impact of selective referral to hospitals on increased travel distance for patients living in urban and rural settings; they concluded that it increases the time to reach the hospital [5, 250]. According to [251, 252], '*the distance for patients to reach the nearest hospital varies significantly by region, and reconfiguration of emergency services could lead to patients with life-threatening conditions traveling longer distances to the hospital. Concerns have been raised that this could increase the risk of death*'. Patients with respiratory emergencies and heart failures show the greatest association between distance and mortality [251, 252]. However, for urgent life-threatening conditions related to chronic diseases, the resulting increased travel time to the hospital might adversely affect survival [253]. Many studies evaluated the relationship between travel time to the nearest hospital and survival from many chronic diseases [253–255]. Therefore, patient location with respect to hospitals affects the healthcare system through their effect on the time to reach the nearest hospital. Increased time to the closest hospital increases deaths from heart attacks and unintentional injuries, and this finding is robust to several sensitivity checks, especially with some evidence that seniors experience serious difficulty in accessing care [256].

Healthcare service packages

Service provision is an important and attractive part of telemedicine because of the treatment process of patients in healthcare. Improving patient care has become a priority for all healthcare providers, with the overall objective of achieving a high degree of patient satisfaction [257]. Delivery of services refers to the provision of emergency care in response to personal and community-wide priority problems [9]. As mentioned in Section "Server Based", many studies have focused on improving the efficiency of services provided for specific emergent conditions. Personalised healthcare services can be provided as quickly and accurately as possible to patients with the most urgent needs. Based on the analysis of previous studies, various services are provided to patients with many types of diseases and to patients with chronic heart disease. According to [9], personalisation of healthcare services for chronic diseases can be divided into five packages based on the severity of patients. Thus, the present research reuses this concept and re-qualifies packaging according to the required triage process illustrated in Section "Triage Standards and Guidelines" to provide real healthcare services. Based on our analyses of literature, the packages and related services according to each triage level are illustrated as follows.

Package 1 (Alarm) Providing healthcare services, especially for risk level (red), is the main challenge for the healthcare system. These services are used for viable victims with potentially life-threatening conditions. Risk level requires immediate medical attention and will not survive if not seen soon [258]. A person with a severe chronic heart disease is classified as red. Prepare surgery room, prepare surgery team and prepare surgery doctor are applied to patients at this level, together with many other services as illustrated in Table 4.

Package 2 (Alarm) Patients at the urgent level (orange) require medical attention but not immediately. Injuries are potentially life threatening but can wait until the patients at the risk level (Package 1) are stabilized and evacuated [258]. Constant observation and rapid treatment transport are needed [258]. This package includes many services related to patient emergency, which are illustrated in detail in Table 5.

Package 3 (Directions) Patients at the sick level (yellow) do not require ambulance transport, but they require medical attention when all high-priority patients have been served,

Table 4 Healthcare service package 1 (alarm)

Triage level	Colour	Personalisation Services	Description	Used by References
Risk	Red	• Emergency Alert	Alerts are produced immediately after measured parameters exceed the specified thresholds at this level [93]	[88, 93, 97, 101, 114, 137]
		• Prepare Surgery Room	Facility within a hospital where surgical operations are carried out in a sterile environment [259]	[9]
		• Prepare Surgery Team	A surgical team is a team of people who perform surgery and related tasks. Roles in the team include surgeon, surgical assistant, surgical technologist, nurse and anaesthesiologist [260]	[9]
		• Prepare Surgery Doctor	In medicine, a surgeon is a medical doctor who performs surgical operations [259]	[9]
		• Contact Doctor	Contacts doctor to help patients make medical decisions with confidence [261]	[97, 99, 101]
		• Prepare O_2 Supplier	Gets oxygen to help patients breathe easier [259]	[9]
		• Send Ambulance	The ambulance service is about getting patients to where they need to be cared for in emergency situations [262]	[5, 97, 101]
		• Notify Relatives	Delivery of the news of a patient to relatives in emergency cases	[92–94, 101]
		• Provide Medications	A drug or other form of medicine that is used to treat or prevent disease [259]	[9, 97, 101]
		• Provide First Aid	Provide first-aid operations while the patient is in the ambulance [97]	[97]

treated, transported and/or discharged as needed. Classified patients typically require very little medical aid if any, and their injuries are minor. They can walk, function freely without assistance, are cognisant and can respond accurately to questioning [263]. The services in this section are illustrated in Table 6.

Package 4 (Directions) Patients at the cold state level (blue) require minor treatment and advice for supervised medication but do not require ambulance transport [263]. The services in this section are illustrated in Table 7.

Package 5 (Directions) Patients with normal level (green) do not require treatment, and their vital signs are stable. The services in this section are illustrated in Table 8.

As mentioned in Sections "Triage Standards and Guidelines".1 and 2.10.2, TAH is an important factor in a patient's life. The healthcare services in the packages above can be provided by using an mHealth doctor based on the triage level. Therefore, the variation in time between patient location t each hospital and the wide variation in service availability from one hospital to another represent a multi-complex decision problem. Accordingly, the multi-decision making

Table 5 Healthcare service package 2 (alarm)

Triage level	Colour	Personalisation Services	Description	Used by References
Urgent	Orange	• Emergency Alert	Alerts are produced immediately after measured parameters exceed the specified thresholds at this level [93]	[88, 93, 97, 101, 114, 137]
		• Prepare Emergency Room	Prepare a medical treatment facility specializing in emergency medicine, the acute care of patients who are present without prior appointment. The emergency department is usually found in a hospital or other primary care center [179]	[9]
		• Prepare Consultant Section	Prepare consultant section includes diagnosis procedures [259]	[9]
		• Prepare Doctor	Prepare medical doctor who performs diagnosis procedures to provide medication [259]	[9]
		• Contact Doctor	Contact doctors to help patients make medical decisions with confidence [261]	[97, 99, 101]
		• Prepare O_2 Supplier	Get oxygen to help patients breathe easier [259]	[9]
		• Send Ambulance	The ambulance service is about getting patients to where they need to be cared for in emergency situations [262]	[5, 97, 101]
		• Notify Relatives	Delivery of the news of a patient to relatives in emergency cases	[92–94]
		• Provide Medications	A drug or other form of medicine that is used to treat or prevent diseases [259]	[9, 97, 101]
		• Provide First Aid	Provide first-aid operations while the patient is in the ambulance [97]	[97]

Table 6 Healthcare service package 3 (direction)

Triage level	Colour	Personalisation Services	Description	Used by References
Sick	Yellow	• Emergency Alert	Alerts are produced immediately after measured parameters exceed the specified thresholds at this level [93]	[88, 93, 97, 101, 114, 137]
		• Prepare Consultant Section	Prepare consultant section includes diagnosis procedures [259]	[9]
		• Prepare O_2 Supplier	Get oxygen to help patients breathe easier [259]	[9]
		• Prepare Doctor	Prepare medical doctor who performs diagnosis procedures to provide medication [259]	[9]
		• Provide Medications	A drug or other form of medicine that is used to treat or prevent diseases [259]	[9, 97, 101]

method must be used as a recommended solution to solve this complex situation. The MCDM method is introduced in the next section.

Recommended pathways and solutions for future directions

The new recommendation pathway solution in this article is explained in this part. The supporting reviews are presented as follows. The processes of hospital selection involve simultaneous consideration of multiple criteria (TAH and healthcare services) to evaluate and score hospitals. Hence, adopting candid and structured techniques for decisions utilising multiple criteria might increase the quality of the decision making and method set, which is known under the collective heading MCDA. They are usable in these situations. Consequently, beneficial methods that deal with multi-criteria decision making (MCDM) issues are presented as recommended pathways and solutions that collectively help decision makers organise any problem to be solved and to apply evaluations, analyses and rankings [264].

Definition and significance of MCDM

MCDM is defined in the book of Keeney and Raiffa [265] as '*an extension of decision theory that covers any decision with multiple objectives. A methodology for assessing alternatives on individual, often conflicting criteria, and combining them into one overall appraisal…'* Meanwhile, Stewart and Belton [266] defined MCDM as an umbrella term to describe a collection of formal approaches, which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter.

MCDM is the most well-known decision-making methodology, and it is a branch of operations research (OR) that deals with decision problems with respect to decision criteria [267, 268]. MCDM involves structuring, planning and solving decision problems by using multiple criteria [267]. The goal is to help decision makers address such problems [269]. MCDM is often expressed as a process using a set of quantitative and qualitative methods that explicitly and simultaneously consider multiple and often conflicting factors [270, 271]. The use of MCDA is rapidly increasing due to its capability to improve the quality of decisions by making the decision process more efficient, rational and explicit than conventional processes [272]. The aims of the MCDM are as follows: (1) help data miners select the best alternative; (2) rank the alternatives in a decreasing order of performance and (3) categorise the viable alternatives among a set of available alternatives [264]. Accordingly, the suitable alternatives are scored.

MCDM was first used in decision making in healthcare in May 2014 according to the recommendation of the Health Science Policy Council. MCDM includes a wide range of methodological approaches from operations research and is now being used increasingly in the healthcare sector. The task force objective was to offer a foundational report on the topic and an MCDM primer and focus on initial recommendations on how to best use MCDM methods to support decision making in healthcare. In any rank in MCDM, a definition of fundamental terms is needed and must contain the decision matrix

Table 7 Healthcare service package 4 (direction)

Triage level	Colour	Personalisation Services	Description	Used by References
Cold State	Blue	• Emergency Alert	Alerts are produced immediately after measured parameters exceed the specified thresholds at this level [93]	[88, 93, 97, 101, 114, 137]
		• Medication Reminder	Advice for medication reminder [9]	[9, 101]

Table 8 Healthcare service package 5 (direction)

Triage level	Colour	Personalisation Services	Description	Used by References
Normal	Green	• Message: 'You are in good health'	Patient's conditions are in a good state	[9]

and its attribute [273]. An evaluation matrix includes n attributes and m alternatives, which need to be identified. The intersection of an attribute and alternative is defined as z_ij. Hence, we have a matrix (z_ij) _ (m*n) explained as follows:

$$DM = \begin{matrix} \\ Y_1 \\ Y_2 \\ \vdots \\ Y_m \end{matrix} \begin{bmatrix} X_1 & X_2 & \cdots & X_n \\ Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & \\ \vdots & \vdots & \vdots & \vdots \\ Z_{m1} & Z_{m2} & \cdots & Z_{mn} \end{bmatrix} \quad (1)$$

where Y_1, Y_2, …. , Y_m are suitable alternatives that decision makers need to rank, that is, hospitals. X_1, X, …, X_n are the attributes/criteria against which the performance of all alternatives are evaluated, that is, multi-services and TAH within the dataset. z_{ij} is the rating of alternative Y_i with respect to criterion X_j, and W_j is the weight of criterion X_j.

For example, we assume that DM is the decision matrix utilised to score and rank the alternatives Yi according to X_j. Table 9 shows an example of multiple-attribute problems expressed in a previous article [274].

The data in the flowchart cannot be easily evaluated due to the large numbers of *X2* and *X3* (Fig. 8).

The process of decision making can be enhanced by involving stakeholders and decision makers and providing the process with structure and support. Using explicit, structured methods for decisions concerning multiple criteria can increase the decision-making quality and set of techniques. This set of techniques offers clarity on which criteria are relevant, the importance attached to each and how to involve this information in a framework for evaluating existing alternatives. By doing so, they can help increase the transparency, consistency and validity of the decision. MCDM has the potential to contribute to a fair, transparent and rational priority-setting process.

Table 9 Example of multiple-attribute problems

Y_i X_j	X1	X2	X3	X4	X5	X6
Y1	2	1500	20,000	5.5	5	9
Y2	2.5	2700	18,000	6.5	3	5
Y3	1.8	2000	21,000	4.5	7	7
Y4	2.2	1800	20,000	5	5	5

Applications of MCDM

MCDM is widely used in several fields for different applications. It finds and ranks suitable solutions to select the appropriate alternative [275]. Its areas of application include energy management [276], energy planning [277], transportation [278], geographical information systems [279, 280] and resource and budgeting allocation [281].

Overview of using MCDM in healthcare

The use of MCDM in healthcare has flourished recently; MCDM is a popular methodology to assist in decision making in healthcare [271, 282–288]. With different MCDM techniques, healthcare decision makers can improve their decision making by systematically obtaining suitable solutions [289]. The significance of healthcare decision making cannot be confirmed enough because several of these decisions are difficult and involve uncertainties and the elicitation of the values and preferences of stakeholders [282]. MCDM does not mimic or replace medical judgments but is utilised to specify, gather and structure the required information by reviewers to enhance the decision-making process [271]. No crucial solutions are available for enhancing the processes of decision making in healthcare; however, techniques such as MCDM are a step further [282]. Therefore, nowadays, MCDM is considered the new direction and has been applied in various healthcare domains in previous studies.

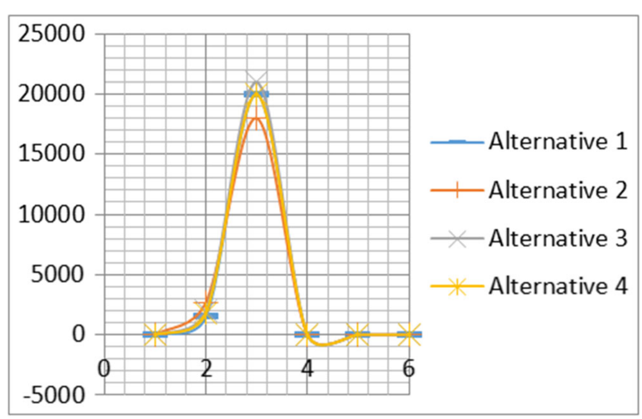

Fig. 8 Graphical representation of the example in Table 9

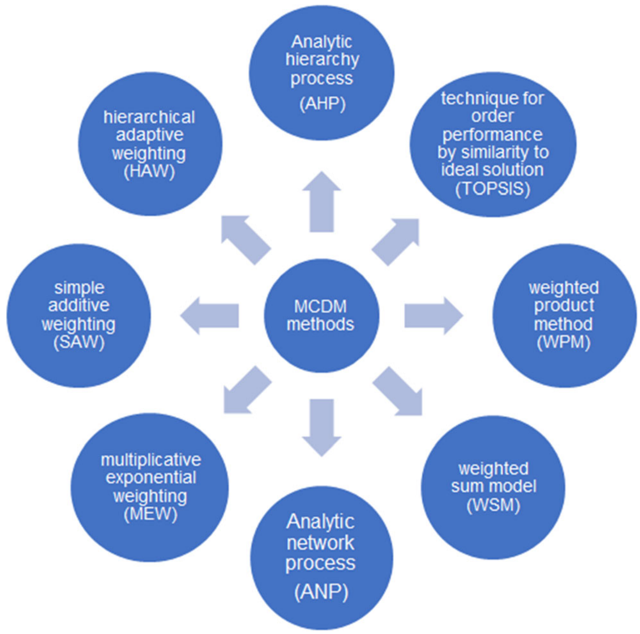

Fig. 9 Most popular MCDM methods

MCDM methods

Various MCDM theories have been discovered. Figure 9 illustrates the most popular MCDM methods that utilise different concepts [290].

The advantages and limitations of these MCDM methods are presented in Fig. 10 according to previous studies [275, 290–310].

To the authors' knowledge, none of the discussed methods has been used to provide healthcare services within mHealth in the telemedicine environment. These methods lack indicators of how well a healthcare service can satisfy the needs of patients through mHealth during the occurrence of various failures on the server side. Another issue with these methods is the non-adoption of a requirement-driven approach, which makes them insufficient for dealing with multi services through distributed hospitals based on decision making [311].

The technique for order of preference by similarity to the ideal solution (TOPSIS) is functionally related to discrete alternative problems. The merit of TOPSIS is its capability to rapidly find the best alternative. Thus, TOPSIS is appropriate for situations with many alternatives and attributes [312]. The chief shortcoming of TOPSIS is the lack of provision for weight elicitation and judgment consistency checking [307]. From this perspective, although TOPSIS decreases pairwise comparisons, its capacity limitation may not significantly dominate the process. Consequently, TOPSIS is applicable for cases with numerous alternatives and criteria. The method is also convenient to use when quantitative or objective data are given. Moreover, TOPSIS is time consuming because it requires significant amounts of time to complete the ranking process [313], and this is a drawback because time is an important factor in the scope of this research (mHealth).

Meanwhile, the multi-criteria analytic hierarchy process (MAHP) method is an effective technique to obtain the relative importance of various criteria with respect to the objective. The multi-layer analytic hierarchy process (MLAHP) is used to set weights for objectives on the bases of the preferences of stakeholders [312], and it is significantly restricted by the capacity of humans for processing information. Therefore, 7 ± 2 would be the comparison ceiling [308]. From this viewpoint, AHP alleviates the requirement for paired comparisons, but its capacity limitation might not significantly dominate this process [314]. AHP can also be used to rank alternatives. The method is also convenient to use when quantitative or objective data are given. It does not require significant amounts of time, which is an important factor in ranking alternatives.

In conclusion, to provide healthcare services by using mHealth in the case of failures on the medical centre side, MAHP is used in this research in two stages. MLAHP was recommended to set weights for the evaluation criteria (healthcare services) on the bases of experts' judgments, and AHP was recommended for ranking hospitals on the bases of experts' judgments to guarantee continued service provision within mHealth. MAHP can be used into two directions in this research. The first stage is the use of MLAHP to extract the weight of importance for each criterion from a pairwise comparison, and the second stage is the use of AHP to rank the alternatives.

Methodological aspects

This section provides an overview and explanation of the methodological aspects of a fault-tolerant system for providing healthcare services during the occurrence of various failures in telemedicine architecture. The identification of the decision matrix within mHealth is the first phase (Section "Identification Phase"), followed by the development phase of a decision matrix for hospital selection based on MAHP (Section "Development Phase"). The last phase is the validation process (Section "Validation Phase"). The proposed methodology is presented in Fig. 11.

Identification phase

This phase aims to identify the targeted tier, the case study and dataset, the new triage, the dummy data for TAH, healthcare services and hospitals. As a result of this phase, the information acquired from the identification analysis is used to propose a decision matrix based on

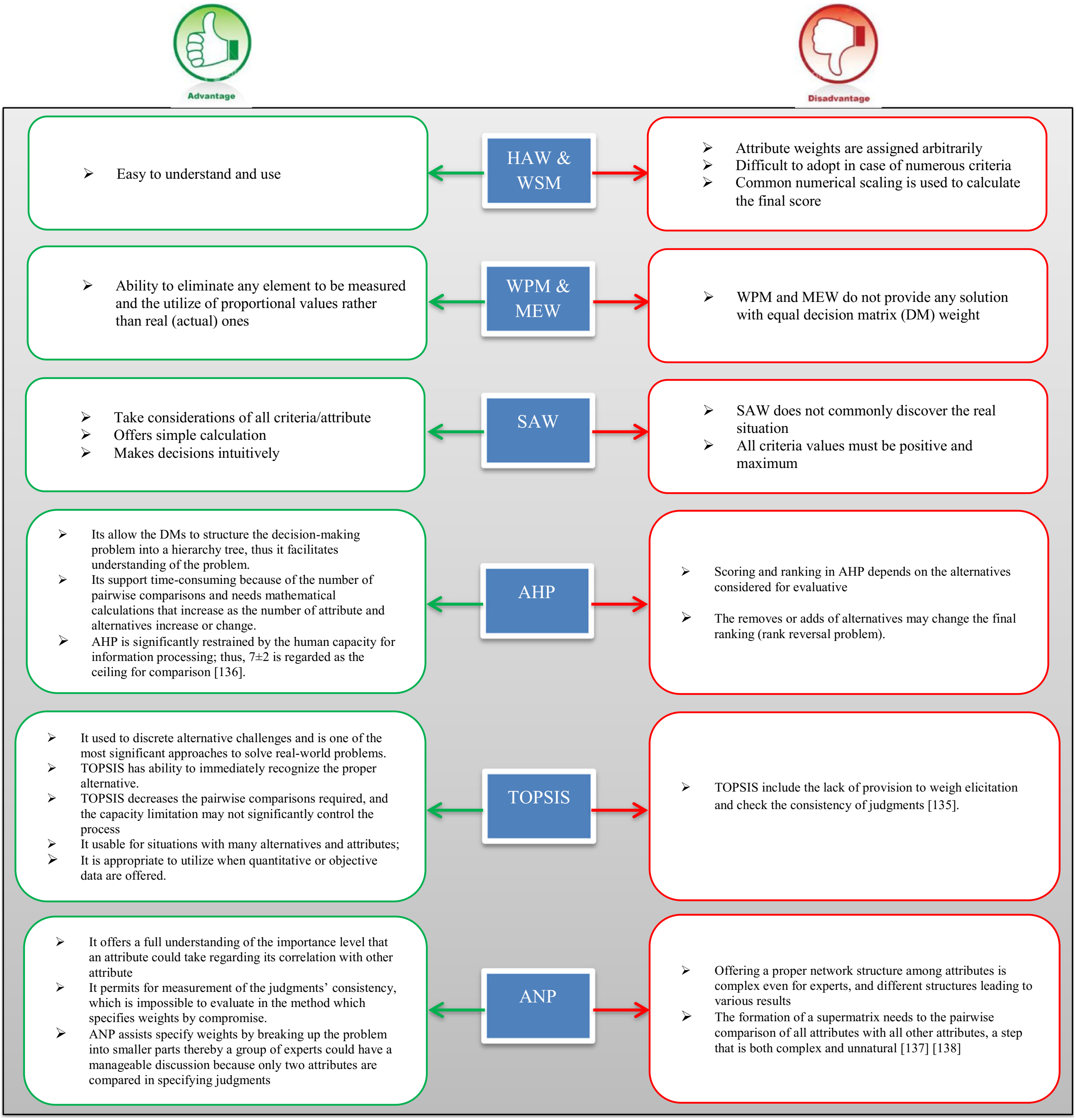

Fig. 10 Advantages and limitations of MCDM methods

the crossover of '(TAH)/multi-services' and 'hospitals' in mHealth (Tier 2) within the telemedicine architecture. The steps involved in this phase are explained in detail in the following sections.

Identify the targeted tier within the telemedicine architecture

The telemedicine architecture utilised in this research contains three tiers. Tier 1 is sensor based, Tier 2 is mHealth, and Tier 3 represents the medical centre that connects to distributed hospitals. Patients can obtain data from the medical sensors and manual inputs (text) in Tier 1 and send them to Tier 2. In Tier 2, medical and public health practices are improved by using mHealth to transfer all information collected from patient sensors and send them to the medical centre (Tier 3) for further processing. In the medical centre, distributed hospitals are connected and controlled by a medical centre server.

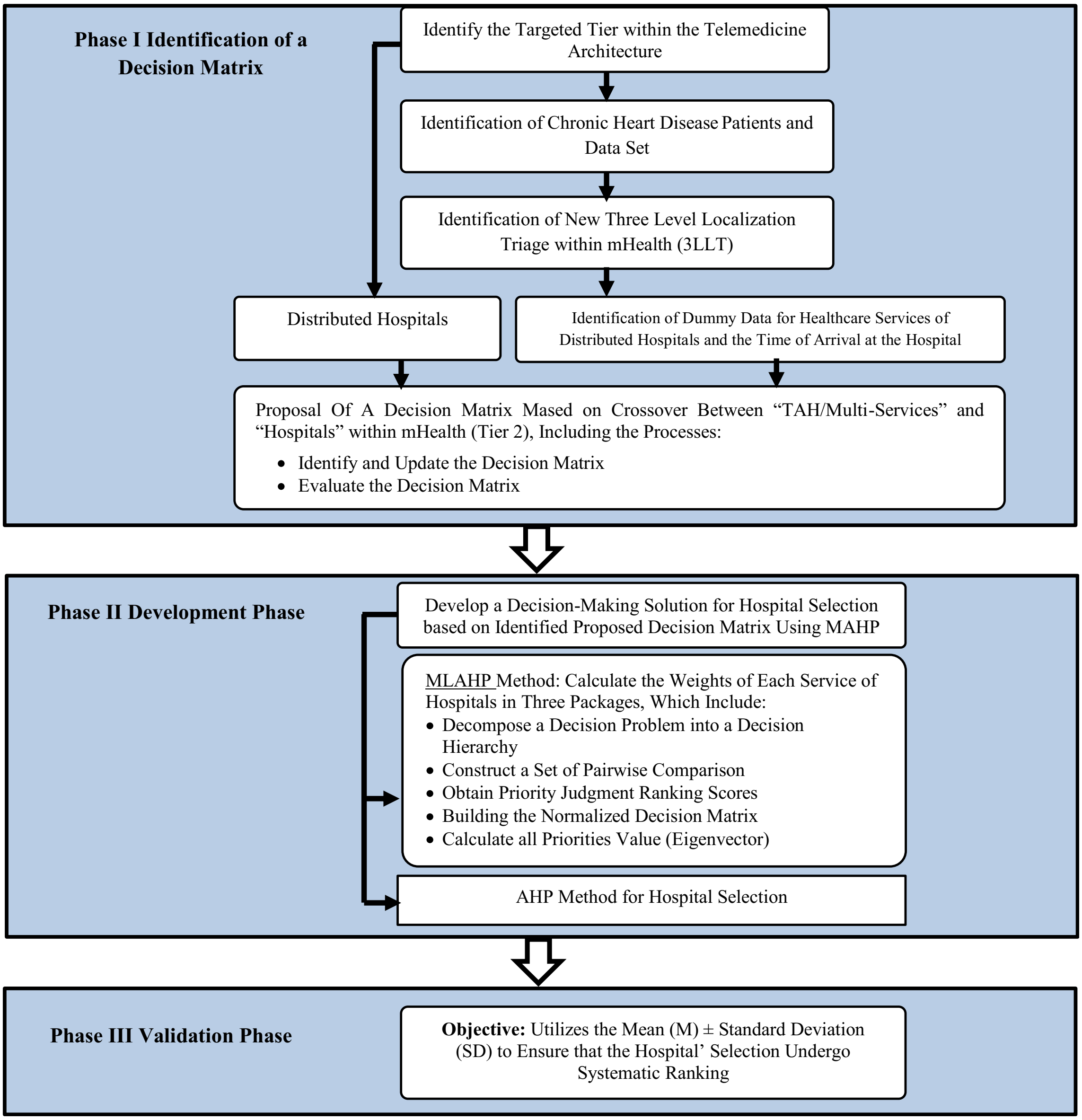

Fig. 11 Methodological aspects and phases

Tier 2 is the targeted tier in this article, and the consideration is that the telemedicine architecture continues to forward healthcare services by using mHealth. Figure 12 shows the flow of healthcare services from the local servers of distributed hospitals to mHealth directly without the medical centre. For remote patients, their vital signs start from the data collection (Tier 1) to mHealth (Tier 2) to provide services from distributed hospitals. Given that mHealth is considered the part where many processes and decisions take place, several issues and problems need to be resolved. The following requirements in mHealth should be fulfilled.

- Accurate healthcare application: Monitor and manage patients' statuses by
  - Alarming the patient when a failure related to Tier 1 occurs.
  - Calculating the triage level to identify appropriate healthcare service packages for patients with chronic heart disease.
  - Such an application can connect directly with distributed hospital servers to provide healthcare services when a failure related to Tier 3 occurs.
- Service weighting: Provide a specific weight to each service for healthcare packages to evaluate hospitals by a set of experts and a decision-making technique.
- Ranking hospitals: Capability to rank and order hospitals according to their available services and TAH and show them in a queue.

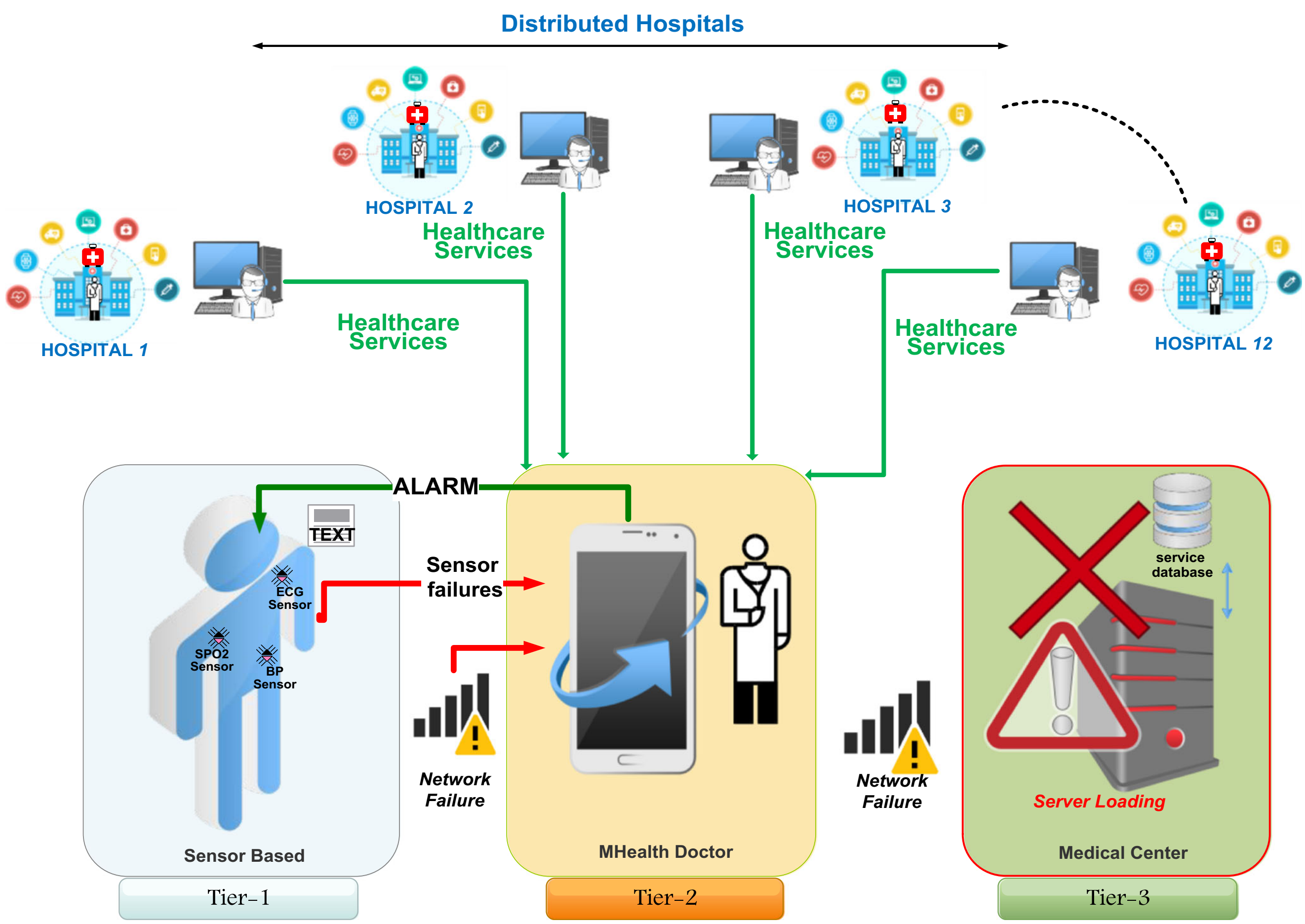

Fig. 12 High-level abstract of the telemedicine architecture during various failures

Identification of patients with chronic heart disease and dataset (CHD dataset)

In this step, the type and number of patients are specified. The patients identified by this research are remote home-monitoring patients with chronic heart disease. Sensors and texts were utilised to measure the patients' vital signs and complaints to monitor and assess their situations. A dataset comprising 500 patients was involved in this research. The dataset was adopted from [9], and such a dataset was used to identify the new triage process in the next section.

Identification of the new three level localization triage within mHealth (3LLT)

According to the telemedicine architecture shown in Fig. 12 and to the analysis at the end of Sections "2.5.2 and 2.10", there is a need to identify a new local triage process within mHealth that can exclude the control of the medical centre server. A new triage known as three level localization triage within mHealth (3LLT) for the telemedicine architecture was created to solve these problems. As mentioned previously, the new triage was derived from [9], and the presented research re-qualified most of the steps of the MSHA algorithm and retained the other steps because they are adaptive to the scope of the requirement of our research. This section gives a detailed explanation of the updated and new steps that are relevant to re-qualify MSHA, resulting in the new 3LLT.

Requirements for constructing 3LLT The required tiers for 3LLT are Tier 1 (sensor based and sources) and Tier 2 (mHealth).

- Tier 1: This step utilises the multi-sources (sensors and text), and the sensors consist of ECG, SpO2 and blood pressure. The transmission of vital signs and other complaints and symptoms is required, and the dataset has already been identified in Section "Sources Used to Measure Patients' Medical Vital Signs" for patients with chronic heart disease.
- Tier 2: The data of patients are transmitted from Tier 1 to Tier 2. In this section, mHealth should fulfil many requirements, such as:

1. Manage and compute the transmitted heterogeneous sources for Tier 1.
2. Detect any failures that occurred in the sensor based on or network related to Tier 1.
3. Estimate the emergency level of the patient.
4. Real-time application with distributed hospital servers in case of:

   a. Medical centre server failure.
   b. Network failure between mHealth and the medical centre server.
5. Off-time application in case of:

   a. Network failure between mHealth and distributed hospital servers.
   b. Medical centre server failure.
   c. Network failure between mHealth and the medical centre server.
6. Provide a computation method that can satisfy all these requirements by applying the data fusion method.

3LLT workflow All data from the sensors are collected by mHealth. mHealth can detect any failure related to Tier 1 and alarm the patient. Any disruption that occurs in transmitting the vital signs of any sensor can alarm the patient by adding a new layer algorithm. Then the data are fused in the fusion module. The outcome of this module recognizes the emergency level of the patient, resulting in four outputs: triage level, triage code (TC), healthcare service packages and alarm.

The module in mHealth processes the TC value and all the gathered data and mimics a triage system that categorises patients based on their status. The TC value is used for linking with appropriate healthcare service packages. Therefore, the triage process is performed locally within mHealth, and there is no need to send the TC value to Tier 3 for further processing. Four important terms regarding to chronic heart disease according to non-sensory features were provided in [9]. These terms are chest pain evaluation, assessment of shortness of breath and palpitation, and determination of whether the user is at rest or exercising. The user is asked four questions that can be answered by yes or no. In the fusion module, features are extracted from the patients' answers and fused through the

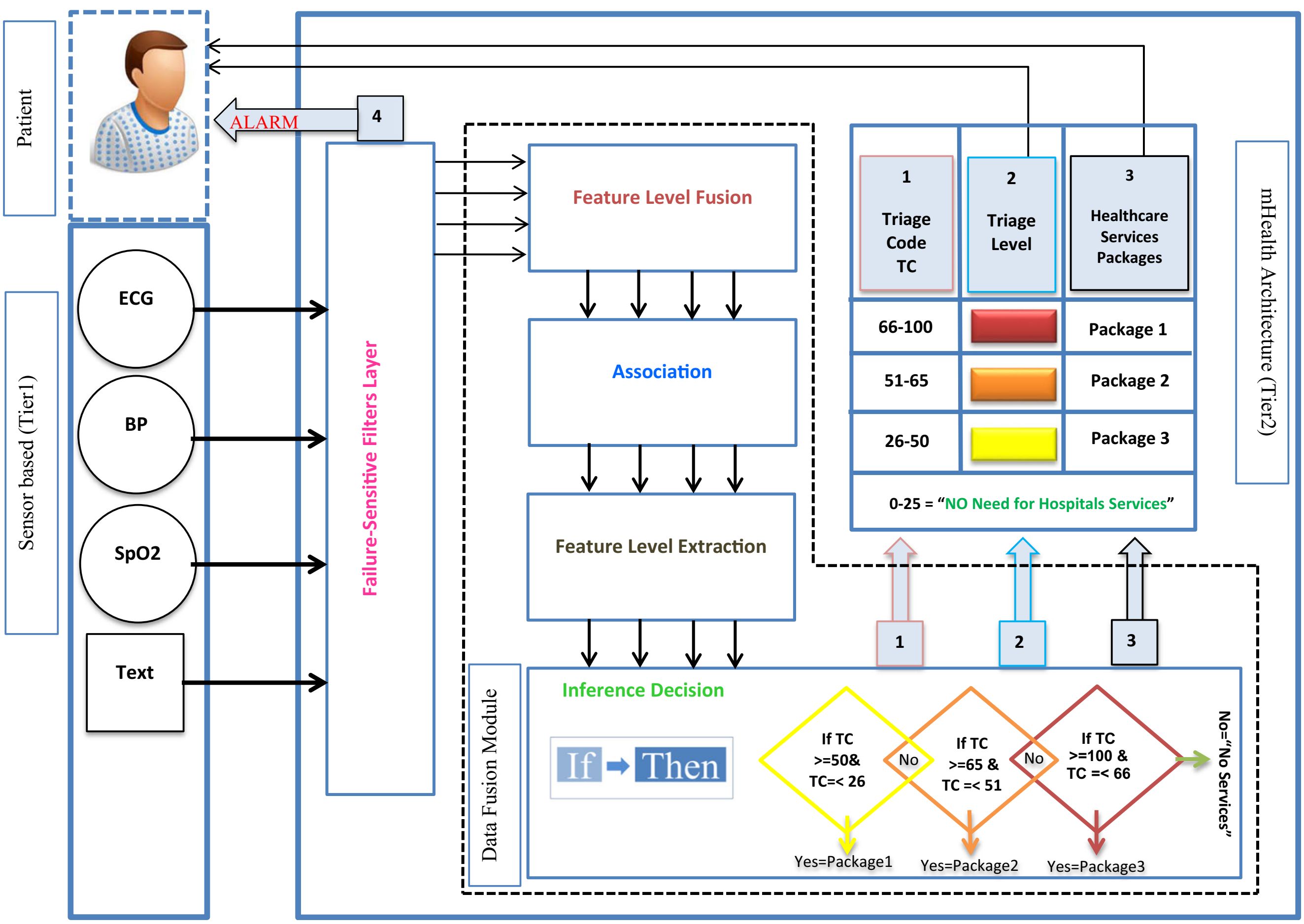

Fig. 13 General scheme of 3LLT within mHealth

Table 10 Healthcare service package, triaging levels and TC value

TC Indication			Triage level	Hospitals Services	Healthcare Services Packages
Colour	Name	TC value			
(red)	Red	66-100	Risk	Prepare Surgery Room, Prepare Surgery Team, Prepare Surgery Doctor, Prepare O_2 Supplier, Send Ambulance, Provide Medications	Package 1
(orange)	Orange	51-65	Urgent	Prepare Emergency Room, Prepare Consultant Section, Prepare Doctor, Prepare O_2 Supplier, Send Ambulance, Provide Medications	Package 2
(yellow)	Yellow	26-50	Sick	Prepare consultant Section, Prepare O_2 Supplier, Prepare Doctor, Provide Medications	Package 3
--------		0-25	NO need for provided Real Healthcare Services Packages from hospitals		
Alarm is given to patient in case of sensor or network failures in Tier1					

Alarm is given to patient in case of sensor or network failures in Tier1

sensor features. Fig.ure 13 illustrates the general scheme of the new triage (3LLT) based on the MSHA algorithm.

Table 11 If–then statements integrated with the data fusion algorithm

Rule Number	Condition of Rule
Rule 1	IF TC value > = 0 AND IF TC value = <25 THEN the patient is Cluster (Normal level)
Rule 2	IF Sick value IS > than Urgent Value AND IF Sick value IS > than Risk Value. THEN the (triage level is Cluster ((Sick level).
Rule 3	IF Urgent value IS > than Sick Value AND IF Urgent value IS > than Risk Value. THEN the (triage level is Cluster ((Urgent level).
Rule 4	IF Risk value IS > than Sick Value AND IF Risk value IS > than Urgent Value. THEN the (triage level is Cluster ((Risk level).
Rule 5	IF patient IS Normal THEN no need for hospital services
Rule 6	IF patient IS Sick THEN the package are 3
Rule 7	IF patient IS Urgent THEN the package are 2
Rule 8	IF patient IS Risk THEN the package are 1

Data fusion module The 3LLT fusion is also based on the fundamentals of data fusion. The presented research adds another layer to the old module and keeps the other blocks as they are (feature extraction, data alignment, data association and state estimation and prediction). The new block (failure-sensitive filters) is explained in below. Fig. 13 illustrates the process of identifying the triage level linked with healthcare service packages in mHealth by using the dataset of a patient with chronic heart disease.

- Failure-sensitive filters: The data transferred from each sensor from Tier 1 should be assigned an alarm in the case of outage occurrence in each sensor. These filters are for detecting sensor or network failures between Tiers 1 and 2.

Output of the data fusion module The outputs of this module have four types of decisions: triage level, TC value, healthcare service packages and alarm, as shown in Table 10.

- TC: The sum of all the scores of the features in MSHA is considered as the TC value. The TC value is a parameter used for triaging patients based on their emergency status.

Table 12 Healthcare service algorithm of the 3LLT triage

Input	**Set of patient's request = m**
Output	• Request for processing • Updating the queue • Healthcare service package provided for the request • Alarm the patient for sensor or network failures in Tier 1
Definition	Queue=q, flag=g, reserved healthcare services package=B, Triage Code=pc, processing request=pr, Provided healthcare services=Y.
Stage 1	\\ ***for sensor failure detector and network failure between Tier 1 and Tier 2*** ***find Sensors Within Region Algorithm*** (*i, j, r, nt*) swr ←{ *// swr is the set of sensors within the region* *// centered at (i, j) with the radius it* **foreach** sensor $s \in nt$ *// calculate the distance from the region center (i, j)* *// to the position of the sensor s* (x_s, y_s). d ← $SQRT\,((x_s - j)^2 + (y_s - j)^2)$ **if** d <= r *// s is within the region so its ID is added to the set swr.* swr ← swr U id_y **end** **end** **return** swr // *return the set of sensors found within the region.* **End**

Stage 2	**For** all m ϵ q **do**
	If (g(m) ϵ q =0) {m(i) = m(i++)}
	End for
	For all m ϵ q **do**
	Sort (pc);
	End for
	Pr=m[pc-i];

Stage 3	LoadHealthcare ServicesPackages(); If pc(pr) >=100 AND pc(pr) =<65 THEN B= Cluster (Red); If pc(pr) >= 65 AND pc(pr) =<51 THEN B= Cluster (Orange); If pc(pr) >=50 AND pc(pr) =<26 THEN B= Cluster (Yellow); If pc(pr) >=0 AND pc(pr) =<25 THEN B= Cluster (Normal); B= Cluster (Green); loadmedicalRecord(); LoadPatintHistory(); loadBill();
Stage 4	Loadlocation(); Ectract timeof request(); Ectract Vital_Signs_of_ request(); DoctorProcedure(); Send_(Y)_to_ user(); reports ( ); Set_flag_zero ();

- Triage Level: Three levels of triage are presented in this research. According to the multi-source data fusion algorithm, the result for all features is used with a range of numbers from 0 to 100. These numbers are to determine the triage level.
- Display Healthcare Service Packages: Three appropriate healthcare services packages out of five can be displayed directly through the GUI that appears on the mHealth screen. In the case of network connection failure between mHealth and distributed hospital servers, the patient can determine his/her appropriate healthcare service package as a temporary case until the connection with the hospital servers becomes available again.
- Display Alarm: This type of service is based on the layer of failure-sensitive filters and can be provided to a patient if any sensor fails to transfer the vital signs to mHealth due to various sensor failures or even when a network failure occurs between Tiers 1 and 2. Such an alarm can stimulate the patient to solve this type of failure.

Based on the TC value and the triage level, the multi-source data fusion module can identify and select the most compatible healthcare service package. Three levels of triaging for patients linked with three healthcare service packages are related to the new triage according to the literature discussed in

Table 13 All probability scenarios of healthcare services for package 1

Service Probability Sequences	Prepare Surgery Room	Prepare Surgery Team	Prepare Surgery Doctor	Prepare O_2 Supplier	Send Ambulance	Provide Medications
1	√	√	√	√	√	√
2	√	√	√	√	√	X
.	.	.	.	.	.	.
.	.	.	.	.	.	.
64	.	.	.	.	.	.

Section "Triage Standards and Guidelines".2 and according to the medical symptoms and guidelines of the MSHA algorithm. The presented research excludes the last two levels (cold state and normal) because the patients in both levels do not require services directly from hospitals; in this situation, the patients are only informed that 'real healthcare service packages from hospitals are not needed'.

3LLT algorithm Evidence theory considers the most suitable data fusion technique to combine information from different sources. In this section, the sequence of processing the data of the 3LLT algorithm is presented. The mathematical representation of 3LLT is established using evidence theory and if–then statements according to the mathematical representation of Dempster–Shafer theory (DST).

If–then statements are used to define the three triage levels linked with healthcare service packages. The consequence of the if–then statements is the triage level (Y), as explained in Table 10 and healthcare service packages. To describe the data processing in the new local triage algorithm (3LLT), the new algorithm replaces stage number 3 and integrates evidence theory with if–then statements. It excludes fuzzy c-means (FCM) to reduce time consumption and enhance energy efficiency. Moreover, FCM is not needed because the fuzzy role is a reasoning system in which the notions of truth and falsehood are considered in a graded manner, whereas the process of using fuzzy c-means in MSHA considers classical logic conclusions that are either true or false for linking the TC value with packages. The sequences of the 3LLT algorithm are shown below.

1. Feature extraction stage
2. Evidence theory fusion stage, which includes the establishment of the score values
3. If–then statement stage.

The first stage of 3LLT (updated stage) is for detecting sensor failures. Alarm can be achieved by the layer of failure-sensitive filters according to [315–318].

Triage level calculation linked with healthcare service packages The if–then statements are applied in this stage. The input of this stage is a decimal value for all triage levels, and the outputs are the final triage level and the appropriate healthcare service packages. Table 11 presents the eight sets of designed clusters. Rules 1 to 4 in the first four clusters are used to determine the three triage levels. Rules 5 to 8 in the second four clusters are used to define the three healthcare service packages. The description for each package of healthcare services has already been explained in Table 10. The healthcare service algorithm in the presented research adds a new stage (stage 1) for sensor failure or network failure detection (alarm). The updated healthcare service algorithm in terms of functions is presented in Table 12.

Identification of dummy data for healthcare services in distributed hospitals and TAH

Dummy data can be used as '*a placeholder for testing and operational purposes. For testing, dummy data can also be used as stubs or pads to avoid software testing issues by*

Table 14 All probability scenarios of healthcare services for package 2

Service Probability Sequences	Prepare Emergency Room	Prepare Consultant Section	Prepare Doctor	Prepare O_2 Supplier	Send Ambulance	Provide Medications
1	√	√	√	√	√	√
2	√	√	√	√	√	X
.	.	.	.	.	.	.
.	.	.	.	.	.	.
64	.	.	.	.	.	.

Table 15. All probability scenarios of healthcare services for package 3

Service Probability Sequences	Prepare Consultant Section	Prepare O_2 Supplier	Prepare Doctor	Provide Medications
1	√	√	√	√
2	√	√	√	X
.	.	.	.	.
.	.	.	.	.
16	.	.	.	.

ensuring that all variables and data fields are occupied' [316]. In this research, the proposed scenario for providing healthcare services from distributed hospitals cannot be represented by real data. The real data in the proposed system can be derived only when such a system is working in real-time processing of healthcare services provided by hospitals. Besides, dummy data are widely used in various areas [319, 320], including telemedicine [4, 321, 322]. Therefore, in this section, dummy data are used to represent the availability of healthcare services from distributed hospitals and to represent TAH. These factors represent the criteria in the decision matrix of this research. The description of the three included healthcare service packages is also represented by dummy data in the subsection below.

Dummy data to represent packages 1–3 Dummy data can represent all probabilities of service availability for these packages. Each (√) symbol in the tables below denotes that the service is available in the hospital. The (X) symbol denotes that the service is not available in the hospital. The tables show that these services have different probabilities in each package.

- Package 1 (Alarm): It contains six services and 64 scenarios of healthcare service probabilities for each hospital, as explained in Table 13.
- Package 2 (Alarm): It also contains six services and 64 scenarios of healthcare service probabilities for each hospital, as explained in Table 14.
- Package 3 (Directions): It contains four services and 16 scenarios of healthcare service probabilities for each hospital, as explained in Table 15.

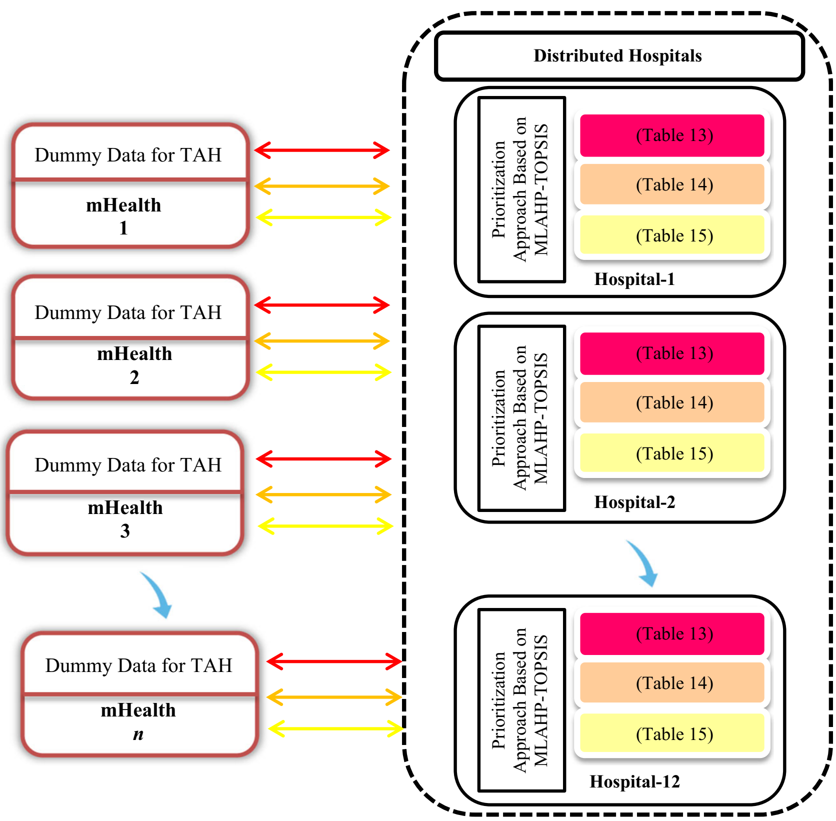

Fig. 14 Identification of dummy data for three healthcare service packages in distributed hospitals and the prioritisation approach

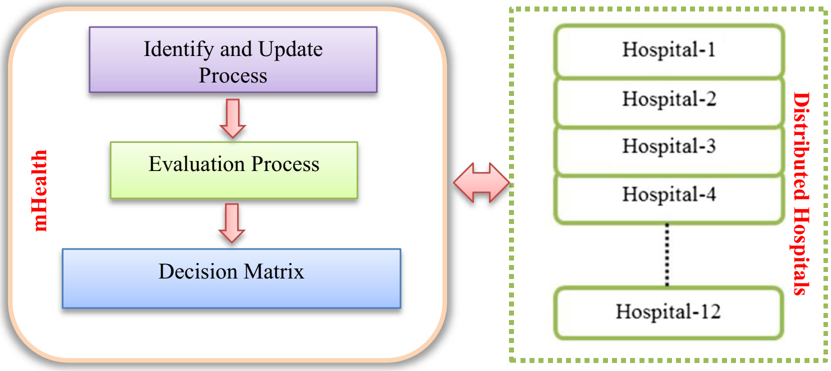

Fig. 15 Overall architecture and design of the decision matrix in mHealth

Dummy data for TAH TAH is an important factor in choosing an appropriate hospital [247–249], especially with the case study of this research which is chronic heart disease. The locations of hospitals are static, whereas the patient is in a mobile environment (dynamic). Motion detector application uses a built-in GPS to detect movements of the patient by social network services. Online social network services have been growing rapidly over the past few years, and they can easily obtain the locations of patients and the time due to the recent increase in the popularity of GPS-enabled mobile devices [323]. Hence, the time between patient location and distributed hospital locations can be represented by using dummy data to fulfil the scenario of decision matrix datasets.

Distributed hospitals

In the medical field, it is sufficient to make a correct medical decision for a patient with chronic heart disease from distributed hospitals [5]. This research adopts 12 hospitals 'as a proof of concept' representing the alternatives in the decision matrix of this study. The position values of these hospitals can also be represented by dummy data. Each hospital contains three packages. Package 1 is for the risk level, package 2 is for the urgent level and package 3 is for the sick level. Moreover, each package is provided to patients according to the patient's triage level.

A problem arises when several patients use mHealth and are admitted at the same time in the same hospital [4]. The selected hospital then needs to prioritise the patients to provide healthcare services to those with a high emergency level rather than to those with other levels. Reference [4] used a prioritisation approach for numerous patients with heart disease according to the most urgent cases, and the approach can solve such a problem by implementation in each hospital server. Moreover, the patients in [4] were scored by depending on a decision matrix using MCDM techniques, namely, integrated MLAHP and TOPSIS. Figure 14 demonstrates the identification of dummy data for the three healthcare service packages within 12 hospitals. Each hospital adopts the prioritisation approach to connect with mHealth. The proposed decision matrix is explained in the next section.

Proposed decision matrix in mHealth doctor

The overall architecture and design of the decision matrix in mHealth are shown in Fig. 15.

Table 16 Decision matrix for package 1 (alarm)

Hospitals	Available Healthcare Services						TAH
Services/ TAH	Prepare Surgery Room	Prepare Surgery Team	Prepare Surgery Doctor	Prepare O_2 Supplier	Send Ambulance	Provide Medications	
Hospital 1	PSR/H1	PST/H1	PSD/H1	POS/H1	SA/H1	PM/H1	TAH/H1
Hospital 2	PSR/H2	PST/H2	PSD/H2	POS/H2	SA/H2	PM/H2	TAH/H2
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Hospital n	PSR/Hn	PST/Hn	PSD/Hn	POS/Hn	SA/Hn	PM/Hn	TAH /Hn

H = Hospital, PSR = Prepare Surgery Room, PST = Prepare Surgery Team, PSD = Prepare Surgery Doctor, POS = Prepare $\mathbf{O_2}$ Supplier, SA = Send Ambulance, PM = Provide Medications, TAH = Time of Arrival at the Hospital

Table 17 Decision matrix for package 2 (alarm)

Hospitals	Available Healthcare Services						TAH
Services/ TAH	Prepare Emergency Room	Prepare Consultant Section	Prepare Doctor	Prepare O_2 Supplier	Send Ambulance	Provide Medications	
Hospital 1	PER/H1	PCS /H1	PD/H1	POS/H1	SA/H1	PM/H1	TAH/H1
Hospital 2	PER/H2	PCS /H2	PD/H2	POS/H2	SA/H2	PM/H2	TAH/H2
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Hospital n	PER/Hn	PCS /Hn	PD/Hn	POS/Hn	SA/Hn	PM/Hn	TAH/Hn

H = Hospital, PER = Prepare Emergency Room, PCS = Prepare Consultant Section, PD = Prepare Doctor POS = Prepare O_2 Supplier, SA = Send Ambulance, PM = Provide Medications, TAH = Time of Arrival at the Hospital

As mentioned previously, hospitals have three packages contained in various healthcare services and can be provided to patients according to the triage level. Healthcare services in distributed hospitals vary in several aspects, and some of these services may be available in several hospitals but unavailable in others. This is a natural scenario of hospital work in the case of increased health demands. Thus, each hospital has a limitation in the provision of services in the case of increased demand for healthcare services. In this context, a distributed hospital scenario (12 hospitals) can overcome this limitation. TAH is a major factor that represents the distance between patients and hospitals. In this research, available services for the selected package of each hospital regarding TAH are gathered and assessed within mHealth. Then, hospitals can compare one another based on available services and TAH via the designed method. A means to achieve this aim is to propose a decision matrix based on the crossover of (1) (TAH)/multi-services and (2) hospital list based on the time to each hospital and the availability of multi-services in each hospital. The identification and updating of the decision matrix are explained in the next section.

Identify and update the decision matrix (DM) The DM for mHealth can be proposed by using healthcare services and TAH (Section "Identification of Dummy Data for Healthcare Services in Distributed Hospitals and TAH") and by using distributed hospitals (Section "Distributed Hospitals"). Each hospital sends updated services to the medical centre server. A copy of these services is kept in the hospitals' databases (local servers). In this research, mHealth can connect directly with distributed hospital servers to identify the available services in each hospital during the occurrence of failures in the medical centre server.

As mentioned in Section "Distributed Hospitals" and shown in Fig. 14, each hospital can connect with mHealth to provide three packages to patients with chronic heart disease based on the triage level. Accordingly, three decision matrixes are proposed for ranking 12 hospitals as follows:

1. First decision matrix: Ranks hospitals according to TAH and service availability in package 1 in each hospital, as shown in Table 16.
2. Second decision matrix: Ranks hospitals according to TAH and service availability in package 2 in each hospital, as shown in Table 17.
3. Third decision matrix: Ranks hospitals according to TAH and service availability in package 3 in each hospital, as shown in Table 18.

Evaluation of DM In this section, the connection of mHealth to hospitals can be implemented directly with the local server of

Table 18 Decision matrix for package 3 (directions)

Hospitals	Available Healthcare Services				TAH
Services/TAH	Prepare Consultant Section	Prepare O_2 Supplier	Prepare Doctor	Provide Medications	
Hospital 1	PCS/H1	POS/H1	PD/H1	PM/H1	TAH/H1
Hospital 2	PCS/H2	POS/H2	PD/H2	PM/H2	TAH/H2
.	.	.	.	.	.
.	.	.	.	.	.
Hospital n	PCS/Hn	POS/Hn	PD/Hn	PM/Hn	TAH /Hn

H = Hospital, PCS = Prepare Consultant Section, POS = Prepare O_2 Supplier, PD = Prepare Doctor, PM = Provide Medications, TAH = Time of Arrival at the Hospital each hospital in order to select an appropriate one. Tables 16, 17 and 18 illustrate the DM that shows the hospitals that are ranked with respect to their available services in each package and TAH. In each DM, the hospitals represent the alternatives, and the services and TAH represent the multi-criteria used to evaluate the hospitals. However, these services exert a different effect on hospital evaluation. Given that these processes involve simultaneous consideration of multi services with respect to the proper weight assigned for TAH and each service to score the hospitals based on the availability of their services, the ranking of hospitals is a multi-criteria problem. Figure 16 shows the new framework of identifying DM within mHealth in the telemedicine architecture. The figure also illustrates the prioritisation approach within each hospital. The development of a decision-making solution for hospital selection is presented in the next section.

In Tier 1 Three biomedical sensors (ECG, SpO2 and blood pressure) are used, and reliable datasets that represent vital signs are sent from these sensors in the sensor-based domain to mHealth in Tier 2. The text inputs associated with chronic heart disease are chest pain, shortness of breath, palpitation and physical condition of the patient (rest or exercising), as mentioned in Section "Identification of Patients with Chronic Heart Disease and Dataset".

In Tier 2 The 3LLT algorithm is used to determine the triage level according to the vital signs of the patient. The output of this algorithm is represented as a TC value for each patient to identify the final triage level and linked with the compatible healthcare service package as explained in Table 10 in Section "Identification of the New Three Level Localization Triage within mHealth (3LLT)".

In distributed hospitals mHealth connects with hospitals to provide healthcare services to patients from 12 hospitals that represent the alternatives in the decision matrix. Each hospital updates the available healthcare services in each package and synchronises the services in its local server as mentioned in Section "Distributed Hospitals". The availability of multi healthcare services in each package in each hospital and the

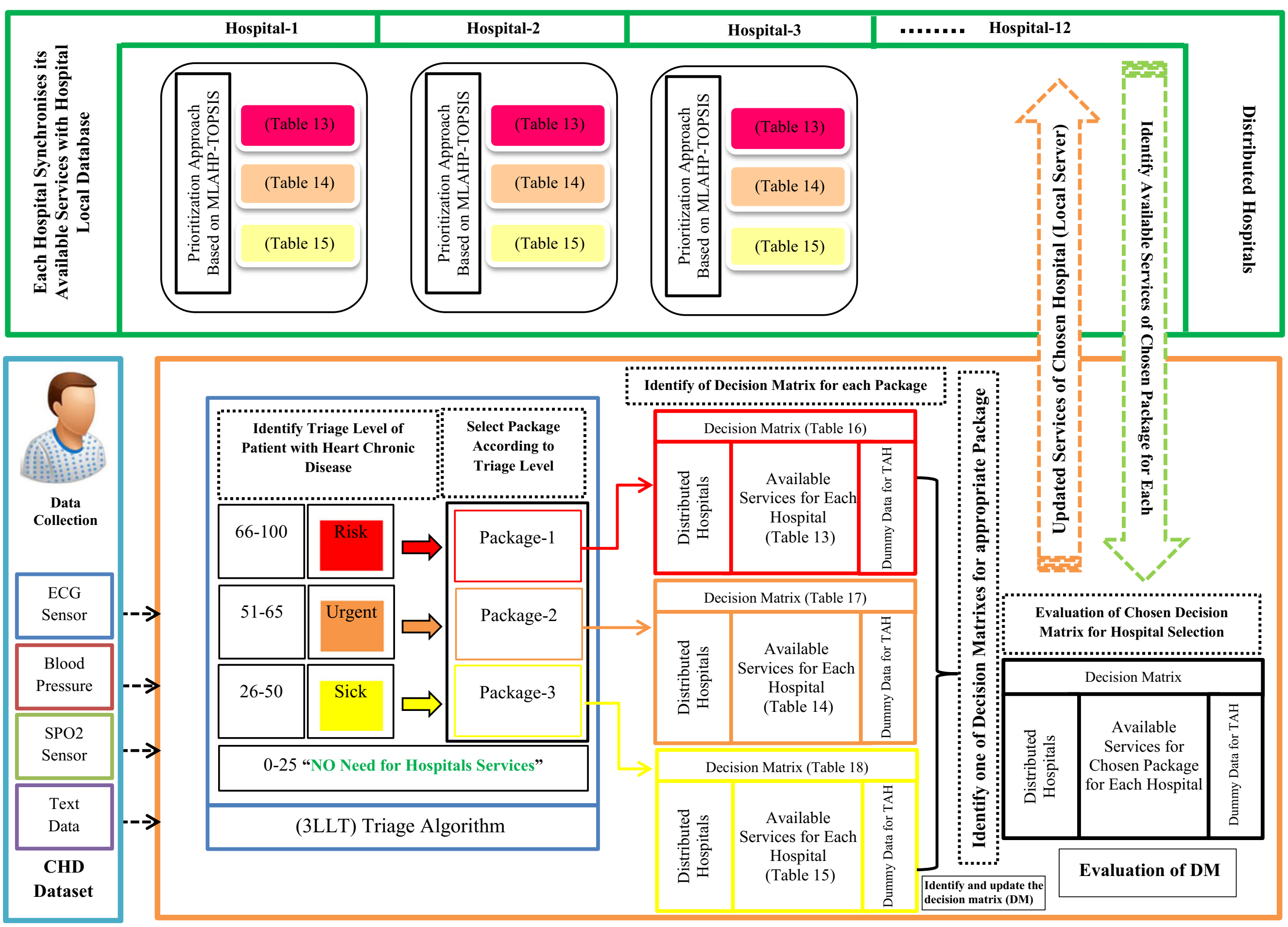

Fig. 16 New framework of identifying the decision matrix within mHealth in the telemedicine architecture

TAH between patient location and hospital location represent the multi-criteria in the decision matrix. In this context, the decision matrix can be built according to the alternatives (12) and multi-criteria (TAH and multi-services).

Identifying the decision matrix and selecting one of them are performed according to the patient triage level by the 3LLT algorithm. For example, if the patient is at risk level, then the decision matrix can be built based on available services in package 1 in each hospital and according to the TAH between patient location and hospital location. Then, ranking of hospitals is performed in the decision matrix to select an appropriate hospital.

When the server is down or network failure occurs between mHealth and the medical server while the connection with hospitals is ongoing, the patient is dealt with by distributed hospitals, and requests are sent to obtain data that represent services. mHealth identifies these services and makes a copy record in the local database for the available services from each hospital. Hence, the decision matrix ranks hospitals according to the last update of package services (available service) for each local server in distributed hospitals. After that, mHealth selects the appropriate hospital and updates the services in the database of the selected hospital (local server). When more than one patient gets the same hospital rank, the prioritisation approach in the selected hospital can deal with these patients.

Development phase

Problems emerge when hospitals have several attributes to offer as healthcare services to patients with chronic heart disease, and each DM can give various weights for these attributes. In typical situations, weights can be distributed by experts (cardiologists). This case is attributed to the varied opinions of experts on the criteria that influence the focus on hospitals. Therefore, hospital selection according to TAH and availability of healthcare services in each hospital is often difficult [5]. In addition, an mHealth system that aims to give ranks to hospitals might provide more weight to less important services, as well as TAH. The ranking of hospitals (particularly, in software development) is a multi-attribute decision-making problem.

For this problem, weights should be set based on the objectives of experts. In this situation, experts are required to set weights that represent different cases. Six evaluators should set the preference weight for three packages. This scenario is recommended for mHealth that ranks hospitals according to TAH and available services. Thus, hospitals with the shortest time to the patient and owns a high level of available services should have high priority, whereas those with the longest time to the patient and owns a low level of available services should have low priority.

To measure the weights of the criteria, several recommended techniques (discussed in Section "Time of Arrival of Patients at the Hospital (TAH)".4) such as AHP, can be used. AHP is a popular MCDM method and highly recommended by researchers [308]. The AHP algorithm produces pairwise comparisons among attributes. Therefore, AHP can decrease the complication of decision making in a safe manner and provides single and group decisions. Traditional AHP deals with one layer of criteria. However, this study involves two main layers (criteria and sub-criteria) that need more than one layer. Thus, multi-layer AHP (MLAHP) is adopted to compute the weights for the criteria and sub-criteria.

The AHP method is also recommended for ranking within mobile platforms (mHealth) because firstly, it is widely adopted for ranking medical matters. Secondly, it can rank a large number of alternatives (hospitals). Thirdly, its computing performance is relatively high and can support real-time data processing, especially when used within mHealth. Besides, using MLAHP for weighting can solve the issue of provision for weight elicitation and consistently checking for judgments within the AHP method. On the basis of MLAHP, the proposed methodology can be used to solve complex multi-attribute measurements and rank problems of hospital selection within mHealth.

Develop a decision-making solution in mHealth for ranking hospitals to provide healthcare services to patients with chronic heart disease based on MAHP

In this section, a detailed description of weighting and ranking methods is presented using MCDM by MAHP. The method involves MCDM methods for ranking hospitals in Tier 2 (mHealth) of the telemedicine architecture. MCDM methods require one (MLAHP) to calculate criteria weights with respect to the goal in order to determine how each of them contributes to this particular decision. Then, the AHP technique is used to rank the hospitals on the basis of quantitative information through which criteria are measured. As a final point, the hospitals are ranked according to their available services and TAH from the first to the last hospital. The structure of the MAHP method for ranking hospitals for each package is shown in Fig. 17.

MLAHP In this stage, several steps are implemented to assign proper weights to TAH and multi-services criteria using MLAHP. The MLAHP procedure includes the following steps [324, 325].

A. Decompose a Decision Problem into a Decision Hierarchy

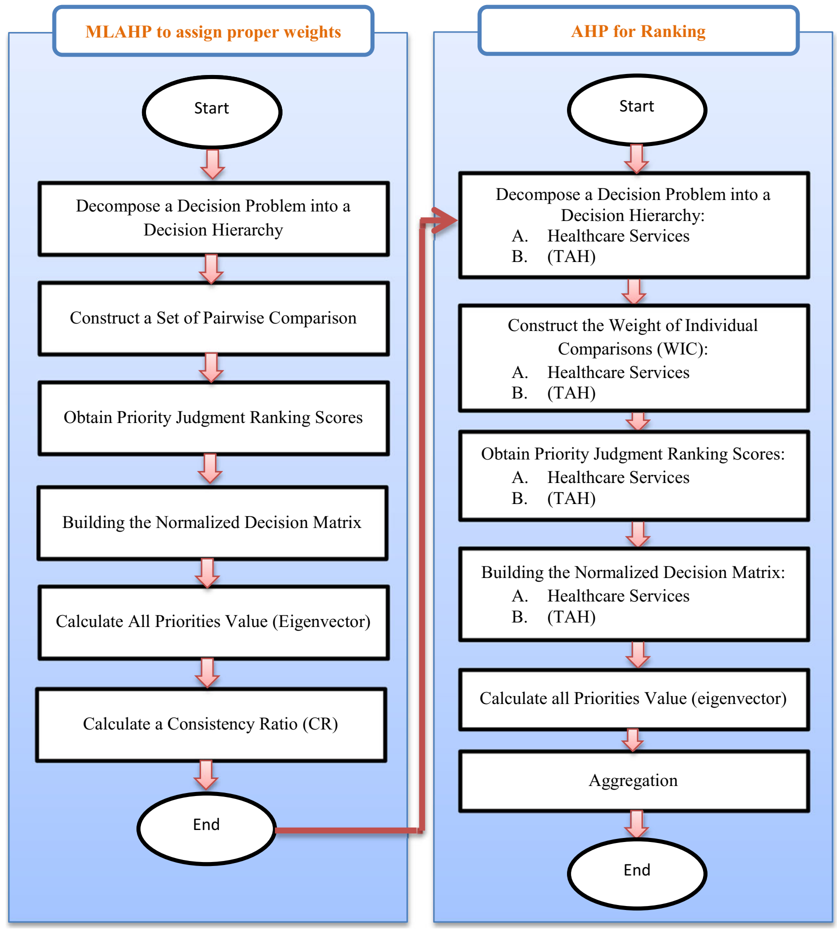

Fig. 17 MLAHP–AHP method for ranking hospitals

To start the MLAHP procedure, problem modelling as a hierarchy consisting of the decision goal, criteria and sub-criteria need to be designed. The hierarchy of the main and sub-criteria used in the MLAHP pairwise comparison for three packages is demonstrated in Fig. 18.

Figure 18 shows the hierarchy (tree) of MLAHP utilised in this research to obtain the weights for three packages. The top of the hierarchy represents the goal, the first layer represents the main criteria and the second layer represents the sub-criteria. The first layer has two main criteria for each package, which are healthcare services and TAH. The second layer in package 1 has six sub-criteria from healthcare services, which are services 1, 2, 3, 4, 5 and 6. The second layer in package 2 has six sub-criteria from healthcare services, which are services 1, 2, 3, 4, 5 and 6. The second layer in package 3 has four sub-criteria from healthcare services, which are services 1, 2, 3, and 4. To obtain the weights, a pairwise comparison is performed between the main criteria for each package with respect to the main goal. Moreover, the sub-criteria of the same parent are compared with respect to the criteria of their parent.

Construct pairwise comparisons To establish a decision, MLAHP builds a pairwise matrix comparison as follows:

$$A = \begin{pmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & \cdots & x_{nn} \end{pmatrix} \quad where, \begin{cases} x_{ii} = 1 \\ x_{ji} = \dfrac{1}{x_{ij}} \end{cases} \qquad (2)$$

Elements X_{ij} are obtained from Fig. 19. The comparisons (relative importance) of each criterion in the first layer or sub-criteria in the second layer are measured according to a numerical scale from 1 to 9 [326, 327]. These relative scales (1 to 9), as shown in Fig. 19, are used to show the experts' judgments for each comparison. Each expert should critically set these judgments based on their experience and knowledge.

B. Obtain priority judgment ranking scores

To show the relative importance of all the criteria and sub-criteria in each package, a pairwise comparison questionnaire is designed and distributed to a geographically diverse

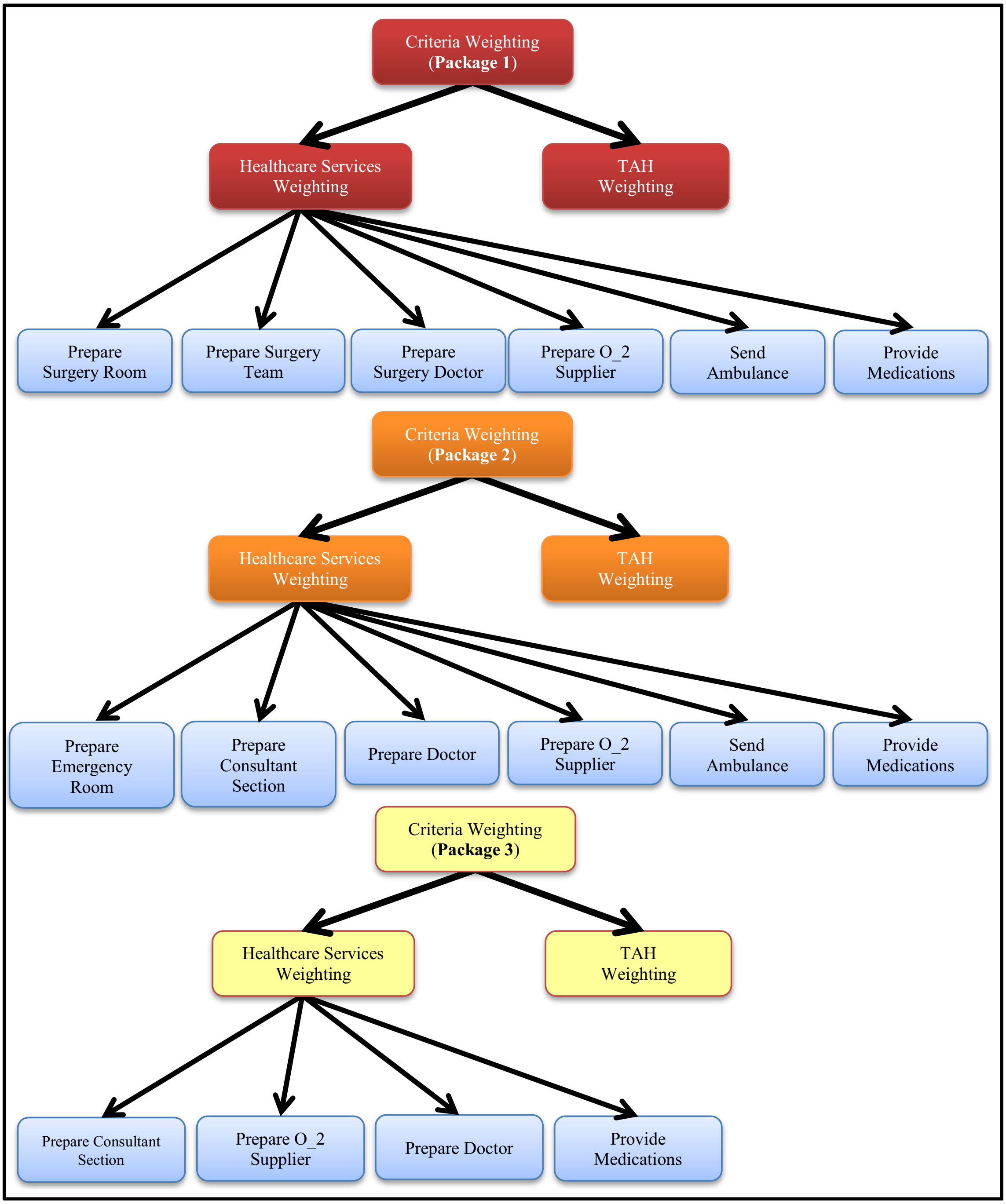

Fig. 18 Hierarchy of MLAHP for healthcare services and TAH

convenience sample of experts with expertise in heart diseases (cardiologists). The experts are asked to show their judgments for the two main criteria (healthcare services and TAH) and secondary criteria (services) for each package by using the nine scales for comparison. They are also asked to show the relative importance for each. A sample of the criteria pairwise comparisons in the evaluation form distributed to experts is illustrated in Fig. 20.

The experts show their judgments for each sub-criterion with respect to healthcare services (parent). In other words, the services in the second layer are compared with respect to their parents in the first layer. Therefore, the experts need to do a pairwise comparison for services in each package under healthcare services. They compare them by following the same pattern for the criteria. The number of required pairwise comparisons is $n \times (n - 1) / 2$, where n is the number of criteria used during evaluation.

At this stage, the decision-making team has already been set up. MLAHP extracts the weight of importance of TAH and healthcare services and the related services for each package

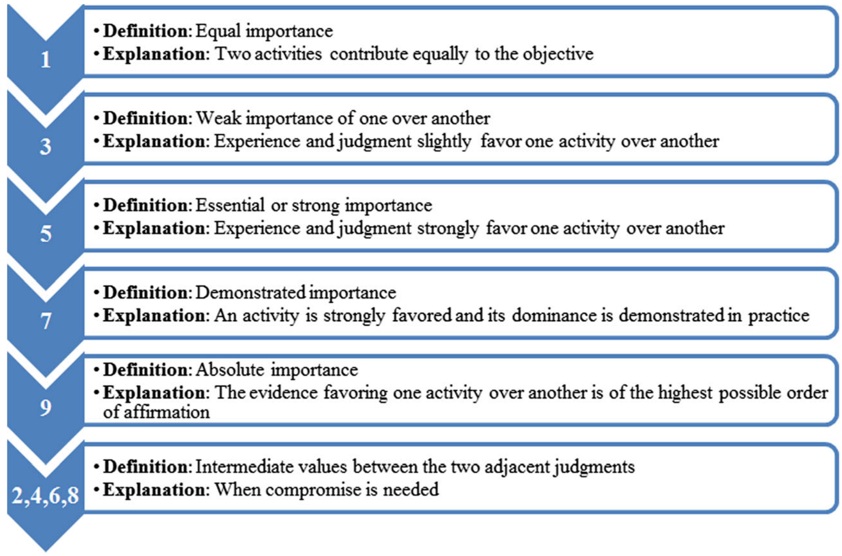

Fig. 19 Nine scales of pairwise comparisons [326, 327]

from the pairwise comparison by using preferences and judgments from the decision-making team. MLAHP is technically valid and does not require a large sample size [328–330]. Hence, in this research, six experts with more than 10 years of experience are selected to show their preferences and judgments on the services used in MLAHP. This must be done in such a manner that it is not reasonable to have the hospital selection depend exclusively on the available services without giving importance to some services more than others as well as TAH. Six copies of the evaluation forms for the three packages are revised by experts for a total of 49 comparisons for TAH and healthcare services. The related services in each package are presented to the experts, and their responses are obtained. At this point, all comparisons for healthcare services and related services for the three packages are made.

C. Building the Normalised Decision Matrix

Every element of matrix A is normalised by dividing each element in a column by the sum of the elements in the same column to create a normalised pairwise comparison matrix A_{norm} . A_{norm} is the normalised matrix of A(1), where A(x_{ij}) is given by Eq. (3). A_{norm} (aij) is expressed as

$$a_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} xij}, \tag{3}$$

$$A_{norm} = \begin{pmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{pmatrix} \tag{4}$$

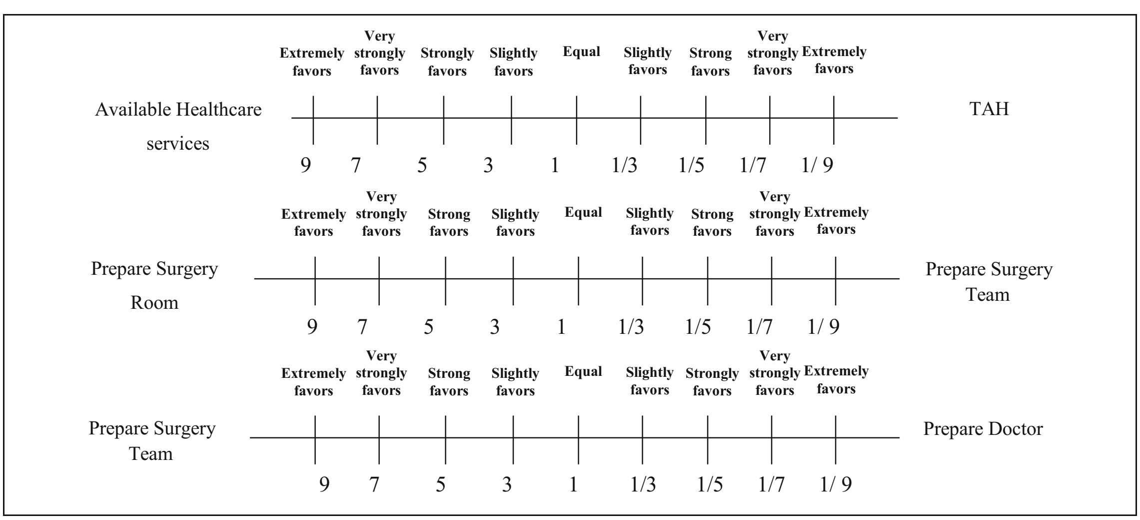

Fig. 20 Sample evaluation form

	Criteria	Original matrix		Normalised matrix		Aggregation	Global Weight
		Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)	Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)		
Each Evaluator	Healthcare Services	HS(1)	HS/TAH	HS(1)/Sum1	(HS/TAH)/Sum2	Sum-HS	W1=Sum_ HS/n
	Time of Arrival at the Hospital	TAH/HS	TAH(1)	(TAH/HS)/Sum1	TAH1/Sum2	Sum_ TAH	W2=Sum_ TAH/n
	Sum	Sum1	Sum2				Sum(W)=1

	Criteria	Original matrix						Normalized matrix						Aggregation	Global Weight
		PSR	PST	PSD	POS	SA	PM	PSR	PST	PSD	POS	SA	PM		
Each Evaluator	PSR	PSR(1)	PSR/ PST	PSR/ PSD	PSR/ POS	PSR/ SA	PSR/ PM	PSR(1)/ Sum1	(PSR/ PST)/ Sum2	(PSR/ PSD)/ Sum3	(PSR/ POS)/ Sum4	(PSR/ SA)/ Sum5	(PSR/ PM)/ Sum6	Sum_ PSR	W1= Sum_ PSR/n
	PST	PST/ PSR	PST(1)	PST/ PSD	PST/ POS	PST/ SA	PST/ PM	(PST/ PSR)/ Sum1	PST1/ Sum2	(PST/ PSD)/ Sum3	(PST/ POS)/ Sum4	(PST/ SA)/ Sum5	(PST/ PM)/ Sum6	Sum_ PST	W2= Sum_ PST/n
	PSD	PSD/ PSR	PSD/ PST	PSD(1)	PSD/ POS	PSD/ SA	PSD/ PM	(PSD/ PSR)/ Sum1	(PSD/ PST)/ Sum2	PSD1/ Sum3	(PSD/ POS)/ Sum4	(PSD/ SA)/ Sum5	(PSD/ PM)/ Sum6	Sum_ PSD	W3= Sum_ PSD/n
	POS	POS/ PSR	POS/ PST	POS/ PSD	POS(1)	POS/ SA	POS/ PM	(POS/ PSR)/ Sum1	(POS/ PST)/ Sum2	(POS/ PSD)/ Sum3	POS1/ Sum4	(POS/ SA)/ Sum5	(POS/ PM)/ Sum6	Sum_ POS	W4= Sum_ POS/n
	SA	SA/ PSR	SA/ PST	SA/ PSD	SA/ POS	SA(1)	SA/ PM	(SA/ PSR)/ Sum1	(SA/ PST)/ Sum2	(SA/ PSD)/ Sum3	(SA/ POS)/ Sum4	SA1/ Sum5	(SA/ PM)/ Sum6	Sum_ SA	W5= Sum_ SA/n
	PM	PM/ PSR	PM/ PST	PM/ PSD	PM/ POS	PM/ SA	PM(1)	(PM/ PSR)/ Sum1	(PM/ PST)/ Sum2	(PM/ PSD)/ Sum3	(PM/ POS)/ Sum4	(PM/ SA)/ Sum5	PM1/ Sum6	Sum_ PM	W6= Sum_ PM/n
	Sum	Sum1	Sum2	Sum3	Sum4	Sum5	Sum6								Sum(W)=1

Where: HS=Healthcare Services, TAH=Time of Arrival of patient at the Hospital, PSR=Prepare Surgery Room, PST= Prepare Surgery Team, PSD= Prepare Surgery Doctor, POS= Prepare O_2 Supplier, SA= Send Ambulance, PM= Provide Medications

Fig. 21 Design of MLAHP measurement steps for weight preferences for package 1

D. Calculate all Priority Values (Eigenvector)

In this step, MLAHP pairwise comparison uses mathematical calculations to convert these judgments to give weights for healthcare services and TAH, and then for each service in each package. After obtaining the responses on the pairwise comparisons, a reciprocal matrix is created from the pairwise comparisons. MLAHP pairwise derives the local priorities for each group at each level which represent the importance of each service in each package with respect to the parent. Then, the global priority for each service is obtained which represent the importance of each service with respect to the goal. The weights of decision factor i can be calculated as Eq. (5).

$$W_i = \frac{\sum_{j=1}^{n} a_{ij}}{n} \ and \ \sum_{j=1}^{n} W_i = 1 \quad (5)$$

where n is the number of the compared elements. The MLAHP measurement steps should be designed to obtain the weights based on the evaluator's preference. Figure 21 presents the MLAHP measurement steps for the weight preferences that are used by the six evaluators for package 1. The other designs of MLAHP measurement steps for weight preferences for packages 2 and 3 are shown in the appendix (Figs. 27 and 28).

E. Calculate the Consistency Ratio (CR)

In this step, the consistency ratio that expresses the internal consistency of the judgments is calculated. Reference [331] defined the following terms to develop a quantitative measure of the degree of inconsistency within a pairwise comparison matrix. The consistency index (CI) is calculated by Eq. (6).

$$CI = \frac{\lambda\ \max - n}{n - 1} \tag{6}$$

The random index (RI) is calculated by Eq. (7).

$$RI = \frac{1.98\ (n-1)}{n}.CI \tag{7}$$

CI measures the degree of inconsistency. RI is the corresponding measure of the degree of inconsistency of a pairwise comparison matrix. The consistency ratio, CR, is defined in Eq. (8).

$$CR = \frac{CI}{RI} \tag{8}$$

CR is the ratio of CI to RI. CR was proposed by [308], [331], and it is a quantitative measure of the degree of inconsistency of a pairwise comparison matrix. A pairwise comparison matrix with a corresponding CR of not more than 10% or 0.1 is acceptable [308, 331, 332]. If the level of inconsistency is unacceptable, then the decision maker should revise the pairwise comparisons or it will be ignored.

AHP method for ranking hospitals In this stage, AHP is used to rank hospitals as suitable for cases with a small number of alternatives (12 hospitals). AHP can rapidly identify the most suitable alternative. The overall weights are derived from MLAHP from Section "Develop a Decision-Making Solution in mHealth for Ranking Hospitals to Provide Healthcare Services to Patients with Chronic Heart Disease Based on MAHP".1 for the three packages regarding TAH. The available alternative scores are ranked in a descending order, and the hospitals are prioritised based on TAH and available healthcare services in each hospital by using the AHP method. Aggregate scores only provide an idea of which hospitals are more appropriate than others. AHP should allocate the scores to each alternative (per hospital) based on the highest and lowest importance for each criterion (service and TAH) within each package. To rank the hospitals in this research, two procedures are applied by using AHP. The first procedure obtains the values of each criterion of services by calculating the weights of individual comparison (WIC) of each service in each package. The second procedure obtains the values of time by calculating the WIC of TAH in each package towards each hospital. The steps of the AHP method in this section for both procedures include the following.

Step 1: Decompose a Decision Problem into a Decision Hierarchy

A. Healthcare Services

To start the AHP procedure, problem modelling is designed as a hierarchy containing the decision goal and criteria. The hierarchy of each criterion (available and unavailable) used in the AHP pairwise for each service within the three packages is achieved. A sample of the hierarchy for one criterion is provided in Fig. 22.

Figure 22 shows the hierarchy (tree) of AHP used in this research to obtain the WIC for each service for the three packages. The top of the hierarchy represents the goal, and the lower layer represents the criteria. There are two criteria for the prepare surgery room service in this figure, which are available (1) and unavailable (0). To obtain the weights for both, an individual comparison should achieved between available (1) and unavailable (0).

B. TAH

To obtain the hierarchy of TAH in each package, this factor depends on the area of the city where the patient is located and on the distance between the patient and hospitals. This scenario can be calculated by dividing the longest city's diameter into four sections. It can also be divided into more or fewer sections, but this research adopts the division of the city's diameter into four sections. The first section is measured as the shortest time, the second section is measured as a short time, the third is a long time and the fourth is measured as the longest time. The importance of patient location varies from one package to another according to the experts' judgments. The more the patient is at the risk triage level, the more important it is to reach the nearest hospital. In this context, the hierarchy for TAH criteria is demonstrated in Fig. 23.

Step 2: Construct WIC

Figure 23 shows the hierarchy (tree) of AHP to obtain the weights of WIC for TAH. The top of the hierarchy represents the goal, and the bottom layer represents the criteria. TAH has four criteria in Fig. 23, which are shortest time, short time, long time and longest time. To obtain their weights, an individual comparison is performed.

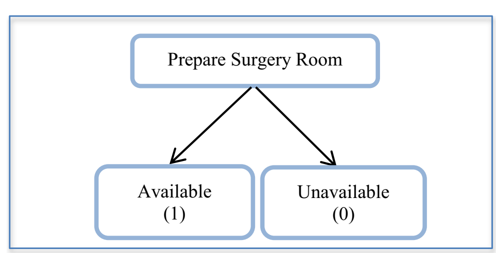

Fig. 22 Sample of the hierarchy for one criterion of services

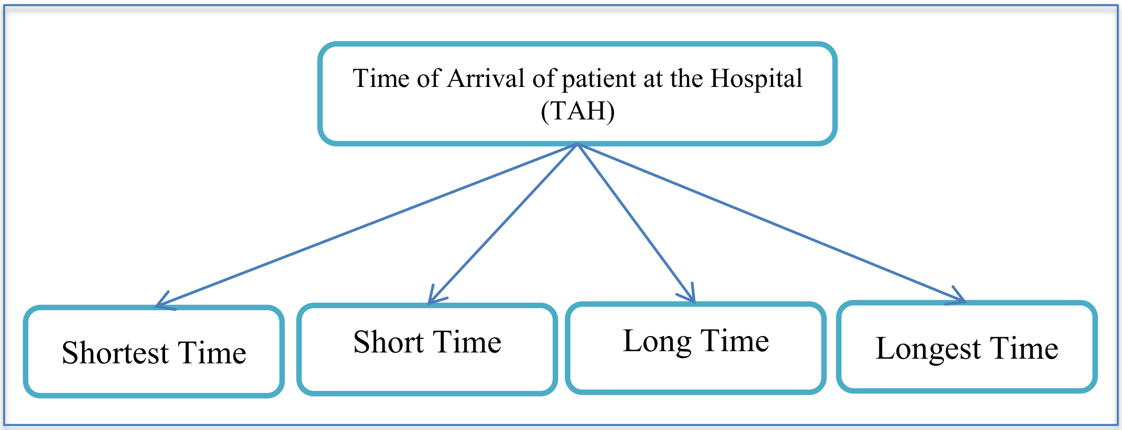

Fig. 23 Hierarchy for TAH criteria

A. Healthcare Services

To establish a decision, AHP performs an individual comparison for each criterion by using Eq. 2. Elements X_{ij} in this equation are obtained from Fig. 19. The comparison (relative importance) of each criterion is measured with itself (same criteria) according to a numerical scale from 1 to 9 [326], [327]. These relative scales (1 to 9), as shown in Fig. 19, are used to show the experts' judgments for each comparison to the same services between available (1) and unavailable (0). Each expert critically sets these judgments based on his/her experience and knowledge.

B. TAH

In the same sequence, AHP performs an individual comparison for each criterion by using Eq. 2. Elements X_{ij} in this equation are obtained from Fig. 19. The comparison (relative importance) of each criterion is measured with itself (same criteria) according to a numerical scale from 1 to 9 [326], [327]. These relative scales (1 to 9), as shown in Fig. 19, are used to show the experts' judgments for each comparison to the variation in time among shortest time, short time, long time and longest time. Each expert critically sets these judgments based on his/her experience and knowledge of TAH in the three packages.

Step 3: Obtain Priority Judgment Ranking Scores

A. Healthcare Services

To show the relative importance of all the services in each package, an individual comparison questionnaire is designed and distributed to a geographically diverse convenience sample of experts with expertise in heart diseases (cardiologists). The experts are asked to show their judgments for the criteria of the service (available and unavailable) for each package by using nine scales to compare each criterion between available and unavailable and show the relative importance of the same criteria with itself. A sample of the criteria for the weight of WIC in the evaluation form distributed to experts is illustrated in Fig. 24.

The experts show their judgments for each service with respect to itself. In other words, each service is compared with itself with respect to available and unavailable in the same service. If the service is available in the hospital, it will be represented by 1; otherwise, it will be represented by 0. At this stage, AHP identifies the weights of WIC for each service, and judgment experts show the importance. Therefore, the experts need to perform an individual comparison for each service in each package under healthcare services. The

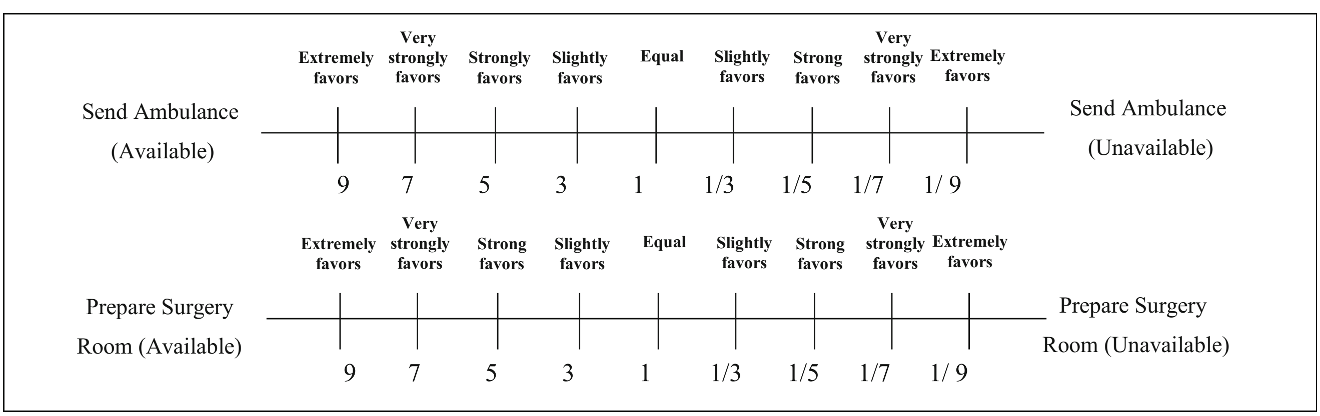

Fig. 24 Sample evaluation form for individual comparison criteria WIC for services

number of required individual comparisons is n × (n − 1) /2, where n is the number of criteria used during the evaluation.

A. TAH

In the same sequence, the experts show their judgments for the TAH criteria for each package by using the nine scales to compare and show the relative importance of each. A sample of the criteria for WIC in the evaluation form distributed to the experts is illustrated in Fig. 25.

The experts show their judgments for each criterion with respect to the parent (TAH). This means the experts should compare the criteria (shortest time, short time, long time and longest time) with one another for each package. The number of required individual comparisons is n × (n − 1) /2, where n is the number of criteria used during the evaluation. AHP identifies the weights. The WIC for TAH should be set by judgment experts to show the importance according to each other.

(Shortest Time) represents the weight of the nearest patient location, (Short Time) represents the weight of a near patient location, (Long Time) represents the weight of a far patient location and (Longest Time) represents the weight of the farthest patient location. In this scenario, each WIC of patient location contains four weights for use in the next stage.

At this stage, the decision-making team should be set up. AHP extracts the weights (WIC) of each service and TAH for each package from the pairwise comparison using preferences and judgments from the decision-making team. This means the first decision matrix for package 1 contains 12 individual comparison weights (six for healthcare services and six for TAH). The same number of comparisons exists in the second decision matrix for package 2. The third decision matrix for package 3 contains 10 individual comparisons (four for healthcare services and six for TAH), as explained in Table 19. Hence, in this research, six experts with more than 10 years of experience are selected to show their preferences and judgments on the services used in the three packages. Six copies of evaluation forms are revised by experts for the three packages with a total of 34 comparisons for services and TAH. The experts' responses should be obtained, At this point, all of the individual comparisons for healthcare services for three decision matrixes have been made.

Table 19 Total number of WIC for all packages

Package / WIC	Number of WIC for services	Number of WIC for TAH
Package 1	6	6
Package 2	6	6
Package 3	4	6

Step 4: Building the Normalised Decision Matrix

A. Healthcare Services

Every element (service) of the decision matrix (either 1 or 0) is normalised by changing each element by its weight obtained from WIC. In other words, each element of the decision matrix that belongs to 0 is converted to the value of S−; it is converted to S* when the element belongs to 1.

B. TAH

Every element of TAH towards each hospital is a number that represents the time between the patient location and the hospital, and every element of TAH in the decision matrix is normalised by changing each element in the decision matrix by its weight obtained from WIC. In other words, each time of the decision matrix that belongs to the range of the shortest time is converted to its weight value. The same applies to the other criteria.

Step 5: Calculate All Priority Values (Eigenvectors)

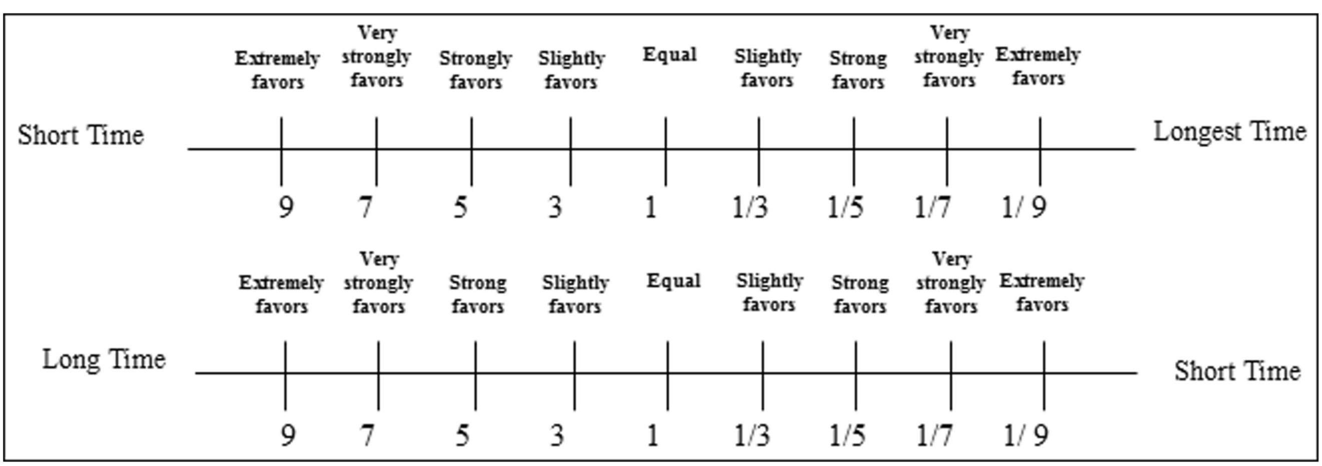

Fig. 25 Sample evaluation form for individual comparison criteria WIC for TAH

In this step, AHP pairwise uses mathematical calculations by multiplying the weight of each service and TAH that is calculated by judgments from MLAHP (Section "Develop a Decision-Making Solution in mHealth for Ranking Hospitals to Provide Healthcare Services to Patients with Chronic Heart Disease Based on MAHP".1) by the element that is normalised. Then, a new value is given for each service and TAH in the decision matrix for all hospitals.

Step 6: Aggregation

In this step, aggregation is calculated by summation of all values for each service and TAH in each row. This value (VS_H) represents the final score of each hospital according to the services and TAH. The available alternative scores should be prioritised in a descending order, and the hospitals should be prioritised based on available healthcare services and TAH in each hospital by using AHP. Figure 26 presents the AHP measurement steps for the weight preferences and the mathematical operations to determine the appropriate hospital for package 1 that should be used for the six evaluators. The other designs of AHP measurement steps for packages 2 and 3 are shown in the appendix (Figs. 29 and 30).

Validation phase

Selecting hospitals is a complicated process for each package, in which the available services in each package in distributed hospitals and TAH have many parts. The availability of services has important roles in the accuracy of these processes. This research adopts two datasets. The first one is for patients with chronic heart disease. It is adopted from [9], the study conducted from the most reliable medical database [333] which has more than 5522 citations (based on March 2017, indexed in Google Scholar) and contains many datasets that are already validated and verified by experts. The second dataset is dummy data which represent the available services, TAH and distributed hospitals. The proposed hospital selection method is validated in the following subsections.

Validation process

The validation of the hospital selection results is set by utilising objective validation. In this stage, statistical methods (mean ± standard deviation) are used to ensure that the hospital selection undergoes a systematic ranking. The ranking results of hospitals are split into four equal groups, as that in the study of [298]. The results are expressed as mean ± standard

	Weights calculated by MLAHP (Fig. 21)							Aggregation
	Healthcare Service Weights						Time of Arrival of patient at the Hospital Weight (WTAH)	
Criteria / Hospitals	WPSR	WPST	WPSD	WPOS	WSA	WPM		
Hospital 1	V_PSR_H1= (WPSR*WIC_PSR)	V_PST_H1= (WPST*WIC_PST)	V_PSD_H1= (WPSD*WIC_PSD)	V_POS_H1= (WPOS*WIC_POS)	V_SA_H1= (WSA*WIC_SA)	V_PM_H1= (WPM*WIC_PM)	V_TAH_H1= (**WTAH** *WIC_TAH)	**Score_H1= Sum(Vs_H1)**
Hospital 2	V_PSR_H2= (WPSR*WIC_PSR)	V_PST_H2= (WPST*WIC_PST)	V_PSD_H2= (WPSD*WIC_PSD)	V_POS_H2= (WPOS*WIC_POS)	V_SA_H2= (WSA*WIC_SA)	V_PM_H2= (WPM*WIC_PM)	V_TAH_H2= (**WTAH** *WIC_TAH)	**Score_H2= Sum(Vs_H2)**
Hospital 3	V_PSR_H3= (WPSR*WIC_PSR)	V_PST_H3= (WPST*WIC_PST)	V_PSD_H3= (WPSD*WIC_PSD)	V_POS_H3= (WPOS*WIC_POS)	V_SA_H3= (WSA*WIC_SA)	V_PM_H3= (WPM*WIC_PM)	V_TAH_H3= (**WTAH** *WIC_TAH)	**Score_H3= Sum(Vs_H3)**
Hospital 4	V_PSR_H4= (WPSR*WIC_PSR)	V_PST_H4= (WPST*WIC_PST)	V_PSD_H4= (WPSD*WIC_PSD)	V_POS_H4= (WPOS*WIC_POS)	V_SA_H4= (WSA*WIC_SA)	V_PM_H4= (WPM*WIC_PM)	V_TAH_H4= (**WTAH** *WIC_TAH)	**Score_H4= Sum(Vs_H4)**
Hospital 5	V_PSR_H5= (WPSR*WIC_PSR)	V_PST_H5= (WPST*WIC_PST)	V_PSD_H5= (WPSD*WIC_PSD)	V_POS_H5= (WPOS*WIC_POS)	V_SA_H5= (WSA*WIC_SA)	V_PM_H5= (WPM*WIC_PM)	V_TAH_H5= (**WTAH** *WIC_TAH)	**Score_H5= Sum(Vs_H5)**
Hospital 6	V_PSR_H6= (WPSR*WIC_PSR)	V_PST_H6= (WPST*WIC_PST)	V_PSD_H6= (WPSD*WIC_PSD)	V_POS_H6= (WPOS*WIC_POS)	V_SA_H6= (WSA*WIC_SA)	V_PM_H6= (WPM*WIC_PM)	V_TAH_H6= (**WTAH** *WIC_TAH)	**Score_H6= Sum(Vs_H6)**
Hospital 7	V_PSR_H7= (WPSR*WIC_PSR)	V_PST_H7= (WPST*WIC_PST)	V_PSD_H7= (WPSD*WIC_PSD)	V_POS_H7= (WPOS*WIC_POS)	V_SA_H7= (WSA*WIC_SA)	V_PM_H7= (WPM*WIC_PM)	V_TAH_H7= (**WTAH** *WIC_TAH)	**Score_H7= Sum(Vs_H7)**
Hospital 8	V_PSR_H8= (WPSR*WIC_PSR)	V_PST_H8= (WPST*WIC_PST)	V_PSD_H8= (WPSD*WIC_PSD)	V_POS_H8= (WPOS*WIC_POS)	V_SA_H8= (WSA*WIC_SA)	V_PM_H8= (WPM*WIC_PM)	V_TAH_H8= (**WTAH** *WIC_TAH)	**Score_H8= Sum(Vs_H8)**
Hospital 9	V_PSR_H9= (WPSR*WIC_PSR)	V_PST_H9= (WPST*WIC_PST)	V_PSD_H9= (WPSD*WIC_PSD)	V_POS_H9= (WPOS*WIC_POS)	V_SA_H9= (WSA*WIC_SA)	V_PM_H9= (WPM*WIC_PM)	V_TAH_H9= (**WTAH** *WIC_TAH)	**Score_H9= Sum(Vs_H9)**
Hospital 10	V_PSR_H10= (WPSR*WIC_PSR)	V_PST_H10= (WPST*WIC_PST)	V_PSD_H10= (WPSD*WIC_PSD)	V_POS_H10= (WPOS*WIC_POS)	V_SA_H10= (WSA*WIC_SA)	V_PM_H10= (WPM*WIC_PM)	V_TAH_H10= (**WTAH** *WIC_TAH)	**Score_H10= Sum(Vs_H10)**
Hospital 11	V_PSR_H11= (WPSR*WIC_PSR)	V_PST_H11= (WPST*WIC_PST)	V_PSD_H11= (WPSD*WIC_PSD)	V_POS_H11= (WPOS*WIC_POS)	V_SA_H11= (WSA*WIC_SA)	V_PM_H11= (WPM*WIC_PM)	V_TAH_H11= (**WTAH** *WIC_TAH)	**Score_H11= Sum(Vs_H11)**
Hospital 12	V_PSR_H12= (WPSR*WIC_PSR)	V_PST_H12= (WPST*WIC_PST)	V_PSD_H12= (WPSD*WIC_PSD)	V_POS_H12= (WPOS*WIC_POS)	V_SA_H12= (WSA*WIC_SA)	V_PM_H12= (WPM*WIC_PM)	V_TAH_H12= (**WTAH** *WIC_TAH)	**Score_H12= Sum(Vs_H12)**

Note: WIC = Weight of individual comparison to represent the criteria of services (available or unavailable) or to represent the criteria of TAH which are (shortest time, short time, long time, and longest time)

- V= Value, H= Hospital, W= Weight, Sum= Summation, Vs_H= All values (V) of all weights for hospital.

Fig. 26 Design of AHP measurement steps for ranking hospitals for package 1 deviation for each group. Mean ($\overline{x}$) is the average and calculated as the sum of all the observed results from the sample divided by the total number, as presented in Eq. (9).

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{9}$$

Standard deviation (s) is a measure that is utilised to quantify the amount of variation or dispersion of a set of data values, as presented in Eq. (10).

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2} \tag{10}$$

Practically, mean ± SD are utilised to ensure that the four groups of hospitals undergo systematic ranking. To validate the result of the test, the hospital scoring is divided into four groups according to the prioritisation result based on the MCDM method. Each group consists of an equal number of hospitals (three) that are selected based on the scoring values from the prioritisation results. The validation process is achieved using two methods based on a statistical platform, and the first group should reach the highest scoring value by measuring the mean and SD. We assume that the first group has the highest mean and SD. To validate the result, a comparison with another three groups is performed. The second group's mean and SD results must be lower than or equal to those of the first group. The third group's mean and SD results must be lower than those of the first and second groups or equal to those of the second group. The fourth group's mean and SD must lower than those of the first, second and third groups or equal to those of the third group. According to the systematic ranking results, the first group is proven statistically to be the highest among all groups. The process is to validate the hospital ranking for one patient. The scope of this research is to rank hospitals individually for 500 patients. Thus, 500 validation processes are achieved for 500 patients. A value of 1 is given for each valid process, and 0 is given to invalid ones. The final value of the validation process for ranking hospitals can be obtained by Eq. (11).

$$fv = \frac{(sum(x)*100)}{500} \tag{11}$$

Where fv denotes the final validation, $sum(x)$is the summation of the valid process and 500 is the number of patients.

Conclusion

The number of studies on telemedicine continues to increase. However, studies related to healthcare service provision in telemedicine applications and mHealth have several limitations that remain unaddressed. mHealth is an emerging topic that warrants further investigation. The main contribution of this work is a comprehensive review for studies related to the topic. A systematic review was conducted in the area of healthcare services in telemedicine applications to determine the gaps and main challenges in providing healthcare services through mHealth (Tier 2). As a result of the taxonomy analysis, specific patterns and general categories were observed in the telemedicine area. The related articles were divided into three major categories: Tiers 1, 2 and 3. We comprehensively analysed articles to highlight the open issues and challenges related to real-time fault-tolerant mHealth systems in telemedicine and address the research gaps. Primary challenges were found in healthcare service provision, such as failure of the medical centre server (Tier 3), scalability in disaster scenes, aging population and network congestion. Most of these challenges are linked to various failures in telemedicine architecture, such as (i) sensor or network failure between Tiers 1 and 2 and (ii) medical centre server failure (Tier 3) or network failure between Tiers 2 and 3. Remote monitoring was also discussed, and chronic heart disease was identified as the case study. Consequently, healthcare service packages for chronic heart disease were identified from literature and addressed in detail. In addition, time of arrival of the patient at the hospital was identified as an important factor in patient life. This review also summarises and outlines the methodological aspects in providing healthcare services during various failures in the telemedicine architecture. The methodological aspects were presented based on three main phases. Each phase corresponds to a major distinct step in producing the anticipated output. Aside from the literature review, this work also identifies the research problem and main objectives, lists the major steps of the identification process to propose a decision matrix within mHealth, shows the development of the proposed decision matrix for hospital selection in the case of medical server failure in Tier 3 and validates the resulting framework. The fault-tolerant system within mHealth enables the telemedicine architecture to continue its intended operation, possibly at a reduced level, rather than failing completely when any part of the system fails. The proposed framework will be simulated and implemented in the future to serve as a guide for providing healthcare services within mHealth during various failures in the telemedicine architecture.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study

Appendix

	Criteria	Original matrix		Normalised matrix		Aggregation	Global Weight
		Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)	Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)		
Each Evaluator	Healthcare Services	HS(1)	HS/TAH	HS(1)/Sum1	(HS/TAH)/Sum2	Sum-HS	W1=Sum_ HS/n
	Time of Arrival of Patient at Hospital	TAH/HS	TAH(1)	(TAH/HS)/Sum1	TAH/Sum2	Sum_ TAH	W2=Sum_ TAH/n
	Sum	Sum1	Sum2				Sum(W)=1

	Criteria	Original matrix						Normalized matrix						Aggregation	Global Weight
		PER	PCS	PD	POS	SA	PM	PER	PCS	PD	POS	SA	PM		
Each Evaluator	PER	PER(1)	PER/ PCS	PER/ PD	PER/ POS	PER/ SA	PER/ PM	PER1/ Sum1	(PER/ PCS)/ Sum2	(PER/ PD)/ Sum3	(PER/ POS)/ Sum4	(PER/ SA)/ Sum5	(PER/ PM)/ Sum6	Sum_ PER	W1=Sum_ PER/n
	PCS	PCS/ PER	PCS(1)	PCS/ PD	PCS/ POS	PCS/ SA	PCS/ PM	(PCS/ PER)/ Sum1	PCS1/ Sum2	(PCS/ PD)/ Sum3	(PCS/ POS)/ Sum4	(PCS/ SA)/ Sum5	(PCS/ PM)/ Sum6	Sum_ PCS	W2=Sum_ PCS/n
	PD	PD/ PER	PD/ PCS	PD(1)	PD/ POS	PD/ SA	PD/ PM	(PD/ PER)/ Sum1	(PD/ PCS)/ Sum2	PD1/ Sum3	(PD/ POS)/ Sum4	(PD/ SA)/ Sum5	(PD/ PM)/ Sum6	Sum_ PD	W3=Sum_ PD/n
	POS	POS/ PER	POS/ PCS	POS/ PD	POS(1)	POS/ SA	POS/ PM	(POS/ PER)/ Sum1	(POS/ PCS)/ Sum2	(POS/ PD)/ Sum3	POS1/ Sum4	(POS/ SA)/ Sum5	(POS/ PM)/ Sum6	Sum_ POS	W4=Sum_ POS/n
	SA	SA/ PER	SA/ PCS	SA/ PD	SA/ POS	SA(1)	SA/ PM	(SA/ PER)/ Sum1	(SA/ PCS)/ Sum2	(SA/ PD)/ Sum3	(SA/ POS)/ Sum4	SA1/ Sum5	(SA/ PM)/ Sum6	Sum_ SA	W5=Sum_ SA/n
	PM	PM/ PER	PM/ PCS	PM/ PD	PM/ POS	PM/ SA	PM(1)	(PM/ PER)/ Sum1	(PM/ PCS)/ Sum2	(PM/ PD)/ Sum3	(PM/ POS)/ Sum4	(PM/ SA)/ Sum5	PM1/ Sum6	Sum_ PM	W6=Sum_ PM/n
	Sum	Sum1	Sum2	Sum3	Sum4	Sum5	Sum6								Sum(W)=1

Where: HS=Healthcare Services, TAH= Time of Arrival patient at Hospital, PER= Prepare Emergency Room, PCS= Prepare Consultant Section, PD= Prepare Doctor, POS= Prepare O_2 Supplier, SA= Send Ambulance, PM= Provide Medications

Fig. 27 Design of MLAHP measurement steps for weight preferences for package 2

	Criteria	Original matrix		Normalised matrix		Aggregation	Global Weight
		Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)	Healthcare Services (HS)	Time of Arrival of Patient at Hospital (TAH)		
Each Evaluator	Healthcare Services	HS(1)	HS/TAH	HS(1)/Sum1	(HS/TAH)/Sum2	Sum-HS	W1=Sum_ HS/n
	Time of Arrival patient at Hospital	TAH/HS	TAH(1)	(TAH/HS)/Sum1	TAH/Sum2	Sum_ TAH	W2=Sum_ TAH/n
	Sum	Sum1	Sum2				Sum(W)=1

	Criteria	Original matrix				Normalized matrix				Aggregation	Global Weight
		PCS	POS	PD	PM	PCS	POS	PD	PM		
Each Evaluator	PCS	PCS(1)	PCS/ POS	PCS/ PD	PCS/ PM	PCS1/ Sum1	(PCS/ POS)/ Sum2	(PCS/ PD)/ Sum3	(PCS/ PM)/ Sum4	Sum_ PCS	W1=Sum_ PCS/n
	POS	POS/PCS	POS(1)	POS/ PD	POS/ PM	(POS/PCS) / Sum1	POS1/ Sum2	(POS/ PD)/ Sum3	(POS/ PM)/ Sum4	Sum_ POS	W2=Sum_ POS/n
	PD	PD/ PCS	PD/ POS	PD(1)	PD/ PM	PD/ PCS)/ Sum1	PD/ POS)/ Sum2	PD1/ Sum3	(PD/ PM)/ Sum4	Sum_ PD	W3=Sum_ PD/n
	PM	PM/ PCS	PM/ POS	PM/ PD	PM(1)	(PM/ PCS)/ Sum1	(PM/ POS)/ Sum2	(PM/ PD)/ Sum3	PM1/ Sum4	Sum_ PM	W6=Sum_ PM/n
	Sum	Sum1	Sum2	Sum3	Sum4						Sum(W)=1

Where: HS=Healthcare Services, TAH= Time of Arrival patient at Hospital, PCS= Prepare Consultant Section, POS= Prepare O_2 Supplier, PD= Prepare Doctor, PM= Provide Medications

Fig. 28 Design of MLAHP measurement steps for weight preferences for package 3

Criteria / Hospitals	Weights calculated by MLAHP (Fig. 27)							Aggregation
	Healthcare Service Weights						Time of Arrival at the Hospital Weight (WTAH)	
	WPER	WPCS	WPD	WPOS	WSA	WPM		
Hospital 1	V_PER_H1= (WPER*WIC_PER)	V_PCS_H1= (WPCS*WIC_PCS)	V_PD_H1= (WPD*WIC_PD)	V_POS_H1= (WPOS*WIC_POS)	V_SA_H1= (WSA*WIC_SA)	V_PM_H1= (WPM*WIC_PM)	V_TAH_H1= (**WTAH** *WIC_TAH)	**Score_H1= Sum(Vs_H1)**
Hospital 2	V_PER_H2= (WPER*WIC_PER)	V_PCS_H2= (WPCS*WIC_PCS)	V_PD_H2= (WPD*WIC_PD)	V_POS_H2= (WPOS*WIC_POS)	V_SA_H2= (WSA*WIC_SA)	V_PM_H2= (WPM*WIC_PM)	V_TAH_H2= (**WTAH** *WIC_TAH)	**Score_H2= Sum(Vs_H2)**
Hospital 3	V_PER_H3= (WPER*WIC_PER)	V_PCS_H3= (WPCS*WIC_PCS)	V_PD_H3= (WPD*WIC_PD)	V_POS_H3= (WPOS*WIC_POS)	V_SA_H3= (WSA*WIC_SA)	V_PM_H3= (WPM*WIC_PM)	V_TAH_H3= (**WTAH** *WIC_TAH)	**Score_H3= Sum(Vs_H3)**
Hospital 4	V_PER_H4= (WPER*WIC_PER)	V_PCS_H4= (WPCS*WIC_PCS)	V_PD_H4= (WPD*WIC_PD)	V_POS_H4= (WPOS*WIC_POS)	V_SA_H4= (WSA*WIC_SA)	V_PM_H4= (WPM*WIC_PM)	V_TAH_H4= (**WTAH** *WIC_TAH)	**Score_H4= Sum(Vs_H4)**
Hospital 5	V_PER_H5= (WPER*WIC_PER)	V_PCS_H5= (WPCS*WIC_PCS)	V_PD_H5= (WPD*WIC_PD)	V_POS_H5= (WPOS*WIC_POS)	V_SA_H5= (WSA*WIC_SA)	V_PM_H5= (WPM*WIC_PM)	V_TAH_H5= (**WTAH** *WIC_TAH)	**Score_H5= Sum(Vs_H5)**
Hospital 6	V_PER_H6= (WPER*WIC_PER)	V_PCS_H6= (WPCS*WIC_PCS)	V_PD_H6= (WPD*WIC_PD)	V_POS_H6= (WPOS*WIC_POS)	V_SA_H6= (WSA*WIC_SA)	V_PM_H6= (WPM*WIC_PM)	V_TAH_H6= (**WTAH** *WIC_TAH)	**Score_H6= Sum(Vs_H6)**
Hospital 7	V_PER_H7= (WPER*WIC_PER)	V_PCS_H7= (WPCS*WIC_PCS)	V_PD_H7= (WPD*WIC_PD)	V_POS_H7= (WPOS*WIC_POS)	V_SA_H7= (WSA*WIC_SA)	V_PM_H7= (WPM*WIC_PM)	V_TAH_H7= (**WTAH** *WIC_TAH)	**Score_H7= Sum(Vs_H7)**
Hospital 8	V_PER_H8= (WPER*WIC_PER)	V_PCS_H8= (WPCS*WIC_PCS)	V_PD_H8= (WPD*WIC_PD)	V_POS_H8= (WPOS*WIC_POS)	V_SA_H8= (WSA*WIC_SA)	V_PM_H8= (WPM*WIC_PM)	V_TAH_H8= (**WTAH** *WIC_TAH)	**Score_H8= Sum(Vs_H8)**
Hospital 9	V_PER_H9= (WPER*WIC_PER)	V_PCS_H9= (WPCS*WIC_PCS)	V_PD_H9= (WPD*WIC_PD)	V_POS_H9= (WPOS*WIC_POS)	V_SA_H9= (WSA*WIC_SA)	V_PM_H9= (WPM*WIC_PM)	V_TAH_H9= (**WTAH** *WIC_TAH)	**Score_H9= Sum(Vs_H9)**
Hospital 10	V_PER_H10= (WPER*WIC_PER)	V_PCS_H10= (WPCS*WIC_PCS)	V_PD_H10= (WPD*WIC_PD)	V_POS_H10= (WPOS*WIC_POS)	V_SA_H10= (WSA*WIC_SA)	V_PM_H10= (WPM*WIC_PM)	V_TAH_H10= (**WTAH** *WIC_TAH)	**Score_H10= Sum(Vs_H10)**
Hospital 11	V_PER_H11= (WPER*WIC_PER)	V_PCS_H11= (WPCS*WIC_PCS)	V_PD_H11= (WPD*WIC_PD)	V_POS_H11= (WPOS*WIC_POS)	V_SA_H11= (WSA*WIC_SA)	V_PM_H11= (WPM*WIC_PM)	V_TAH_H11= (**WTAH** *WIC_TAH)	**Score_H11= Sum(Vs_H11)**
Hospital 12	V_PER_H12= (WPER*WIC_PER)	V_PCS_H12= (WPCS*WIC_PCS)	V_PD_H12= (WPD*WIC_PD)	V_POS_H12= (WPOS*WIC_POS)	V_SA_H12= (WSA*WIC_SA)	V_PM_H12= (WPM*WIC_PM)	V_TAH_H12= (**WTAH** *WIC_TAH)	**Score_H12= Sum(Vs_H12)**

Note: WIC= Weight of individual comparison to represent the criteria of services (available or unavailable) or to represent the criteria of TAH, which are (shortest time, short time, long time, and longest time).
V= Value, H= Hospital, W= Weight, Sum= Summation, Vs_H= All values (V) of each weight for hospital.

Fig. 29 Design of AHP measurement steps for ranking hospitals for package 2

Criteria / Hospitals	Weights calculated by MLAHP (Fig. 28)					Aggregation
	Healthcare Service Weights				Time of Arrival of patient at the Hospital Weight (WTAH)	
	WPCS	WPOS	WPD	WPM		
Hospital 1	V_PCS_H1= (WPCS*WIC_PCS)	V_POS_H1= (WPOS*WIC_POS)	V_PD_H1= (WPD*WIC_PD)	V_PM_H1= (WPM*WIC_PM)	V_TAH_H1= (**WTAH** *WIC_TAH)	**Score_H1= Sum(Vs_H1)**
Hospital 2	V_PCS_H2= (WPCS*WIC_PCS)	V_POS_H2= (WPOS*WIC_POS)	V_PD_H2= (WPD*WIC_PD)	V_PM_H2= (WPM*WIC_PM)	V_TAH_H2= (**WTAH** *WIC_TAH)	**Score_H2= Sum(Vs_H2)**
Hospital 3	V_PCS_H3= (WPCS*WIC_PCS)	V_POS_H3= (WPOS*WIC_POS)	V_PD_H3= (WPD*WIC_PD)	V_PM_H3= (WPM*WIC_PM)	V_TAH_H3= (**WTAH** *WIC_TAH)	**Score_H3= Sum(Vs_H3)**
Hospital 4	V_PCS_H4= (WPCS*WIC_PCS)	V_POS_H4= (WPOS*WIC_POS)	V_PD_H4= (WPD*WIC_PD)	V_PM_H4= (WPM*WIC_PM)	V_TAH_H4= (**WTAH** *WIC_TAH)	**Score_H4= Sum(Vs_H4)**
Hospital 5	V_PCS_H5= (WPCS*WIC_PCS)	V_POS_H5= (WPOS*WIC_POS)	V_PD_H5= (WPD*WIC_PD)	V_PM_H5= (WPM*WIC_PM)	V_TAH_H5= (**WTAH** *WIC_TAH)	**Score_H5= Sum(Vs_H5)**
Hospital 6	V_PCS_H6= (WPCS*WIC_PCS)	V_POS_H6= (WPOS*WIC_POS)	V_PD_H6= (WPD*WIC_PD)	V_PM_H6= (WPM*WIC_PM)	V_TAH_H6= (**WTAH** *WIC_TAH)	**Score_H6= Sum(Vs_H6)**
Hospital 7	V_PCS_H7= (WPCS*WIC_PCS)	V_POS_H7= (WPOS*WIC_POS)	V_PD_H7= (WPD*WIC_PD)	V_PM_H7= (WPM*WIC_PM)	V_TAH_H7= (**WTAH** *WIC_TAH)	**Score_H7= Sum(Vs_H7)**
Hospital 8	V_PCS_H8= (WPCS*WIC_PCS)	V_POS_H8= (WPOS*WIC_POS)	V_PD_H8= (WPD*WIC_PD)	V_PM_H8= (WPM*WIC_PM)	V_TAH_H8= (**WTAH** *WIC_TAH)	**Score_H8= Sum(Vs_H8)**
Hospital 9	V_PCS_H9= (WPCS*WIC_PCS)	V_POS_H9= (WPOS*WIC_POS)	V_PD_H9= (WPD*WIC_PD)	V_PM_H9= (WPM*WIC_PM)	V_TAH_H9= (**WTAH** *WIC_TAH)	**Score_H9= Sum(Vs_H9)**
Hospital 10	V_PCS_H10= (WPCS*WIC_PCS)	V_POS_H10= (WPOS*WIC_POS)	V_PD_H10= (WPD*WIC_PD)	V_PM_H10= (WPM*WIC_PM)	V_TAH_H10= (**WTAH** *WIC_TAH)	**Score_H10= Sum(Vs_H10)**
Hospital 11	V_PCS_H11= (WPCS*WIC_PCS)	V_POS_H11= (WPOS*WIC_POS)	V_PD_H11= (WPD*WIC_PD)	V_PM_H11= (WPM*WIC_PM)	V_TAH_H11= (**WTAH** *WIC_TAH)	**Score_H11= Sum(Vs_H11)**
Hospital 12	V_PCS_H12= (WPCS*WIC_PCS)	V_POS_H12= (WPOS*WIC_POS)	V_PD_H12= (WPD*WIC_PD)	V_PM_H12= (WPM*WIC_PM)	V_TAH_H12= (**WTAH** *WIC_TAH)	**Score_H12= Sum(Vs_H12)**

Note: WIC= Weight of individual comparison to represent the criteria of services (available or unavailable) or to represent the criteria of TAH, which are shortest time, short time, long time and longest time

- V= Value, H= Hospital, W= Weight, Sum= Summation, Vs_H= All Values (V) of each weight for Hospital.

Fig. 30 Design of AHP measurement steps for ranking hospitals for package 3

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