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Research Article

# Smart Real-Time IoT mHealth-based Conceptual Framework for Healthcare Services Provision during Network Failures

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**ABSTRACT**

A series of healthcare problems related to frequent failures in telemedicine architecture, particularly in multi-sensors (Tier 1), medical center servers (Tier 3), and potential failures in network integration between these system components, needed to be addressed. The objective of this research was to present a novel smart real-time IoT mHealth framework within the context of IoT that could select an appropriate hospital during the aforementioned failures. The research methodology involved a new local multi-sensor fusion triage algorithm called the three-level localization triage (3LLT). This aimed to exclude the control process of patient triage and sensor fusion from the medical center, while also alarming failures related to medical body sensors. Additionally, the proposed framework was implemented using the multi-criteria decision-making (MCDM) method, connecting mHealth directly with distributed hospital servers. The distribution of hospitals was determined using the AHP (Analytic Hierarchy Process) based on the crossover between 'healthcare services/time of arrival of the patient at the hospital' and 'hospitals list' to estimate small power consumption. Validation processes were conducted for the proposed framework. The expected output from this research is to enhance the provision of healthcare services during various network failures.

## 1. INTRODUCTION

Various failures within telemedicine architecture can have significant implications for patient well-being. These failures commonly manifest in telemedicine systems, particularly at Tier 1 (sensor-based), Tier 3 (medical center server), and even within the networks connecting these system components [1]. Firstly, sensor characteristics may experience partial or complete failure, leading to degradation in performance or even jeopardizing the stability of the overall systems. Additionally, network failures between Tier 1 and Tier 2 (mHealth) can result in a shortage of data transmission on the client side. In such instances, the measurement of the patient's condition becomes either inaccurate or is entirely unavailable. In scenarios involving a large number of critically ill or injured patients, the provision of healthcare services becomes essential. Scalability is also related to the connection between a Wireless Sensor Network (WSNs) and the server side; thus, this telemedicine system is subjected to a large number of queries, thus network congestion and failure occurs on Tier 3 [2]. In a standard scenario, the medical center server is connected to distributed hospitals to provide healthcare services remotely to patients [3]. Existing mHealth systems focus on delivering solutions for providing healthcare services under normal conditions. However, the issue of sustaining these services in the event of a medical center server failure has not been adequately addressed. When failures occur at Tier 3, or even in its network, mHealth should connect directly with distributed hospitals to select the best one. However, developing a smart real-time IoT mHealth framework that aims to select the best hospital poses a complex decision-making problem. Therefore, understanding the exact criteria for hospital selection and their weights is crucial. To address the specific issues related to hospital selections within fault-tolerant systems, healthcare

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services packages for chronic heart disease, as a case study, can be provided to patients from hospitals through five packages based on triage level. Additionally, the time of arrival of the patient at the hospital (TAH) represents a significant factor for spatially choosing an appropriate hospital for chronic heart disease patients. Thus, the process of hospital selection, considering multi-attributes (healthcare services packages and TAH) with respect to the proper weight assigned for each attribute, is considered a multi-attribute decision matrix, constituting the first issue. Decision makers (doctors) often assign different weights to the mentioned attributes, further increasing the complexity of the task, representing the second issue [4].

The third issue arises from the inverse relationship between the availability of services within hospitals and the arrival time of patients. Whenever services are highly available within hospitals and patient arrival takes a short period, a significant impact on the selection of the best hospital is observed, creating a tradeoff [5]. Finally, the fourth issue emerges from the variation in TAH and service availability among different hospitals. Therefore, the selection process involves simultaneous consideration of multiple attributes of distributed hospitals in different situations, generating data variations, which constitute the fourth issue (the data representing services and TAH vary among hospitals). Consequently, the selection process of hospitals within real-time IoT mHealth is a complex multi-attribute decision-making (MCDM) problem, where each hospital is considered an available alternative for the decision-maker [6]. The research objectives are as follows:

1. To examine current technologies for healthcare services provision, specifically focusing on triage or prioritization based on body sensors in telemedicine applications.
2. To propose a new triage algorithm tailored for chronic heart disease patients, capable of detecting failures at Tier 1
3. To establish a decision matrix for hospital selection based on the newly proposed triage algorithm.
4. To devise and validate an innovative smart real-time IoT mHealth framework founded on the identified decision matrix.

## 2. LITERATURE REVIEW

### *2.1* Tier 1: Sensors

Sensors play an increasingly significant role in medical technologies, aiming to simplify operations and ensure the safety and effectiveness of medical devices. According to [7], the common problems of control congestion in many data networks, such as Wireless Sensor Networks (WSNs), result in packet loss, increased end-to-end delay, and excessive energy consumption due to retransmission. [8] proposed a protocol for congestion detection by adopting multi-biosensors based on the type-2-fuzzy logic system. In [7], the Healthcare Aware Optimized Congestion Avoidance and Control Protocol (HOCA) was introduced for medical health applications, incorporating active queue management and multi-path QoS-aware routing. In [7], an optimized congestion management protocol was proposed for wireless sensor networks through two stages: firstly, avoiding congestion through the Active Queue Management (AQM) scheme and providing Quality of Service (QoS); secondly, using three mechanisms for congestion control.

### 2.2 Tier 3: Security, Privacy, and Remote Monitoring

This category includes two areas: security and privacy, and remote monitoring. In the security and privacy aspect, [9] proposed a mechanism focused on integrity, confidentiality, and fine-grained access to outsourced medical data generated by medical sensor networks. [10] focused on the security of the eHealth society by incorporating a Low-Cost and Secure (LCS) communication system. [11] presented a remote monitoring system, including nano networks inside a patient's body, investigating current trends and security challenges and requirements in the Wireless Body Area Network (WBAN).

The area of remote monitoring includes E-triage server studies and provision of services studies. The E-triage server refers to the triage process located in the on-site rescue control center for managing and monitoring patients' vital signals. In [12], a proposed monitoring system uses a photoplethysmograph in emergency rooms, allowing healthcare professionals/physicians to collect patients' pulse rate and temperature in a comfortable and constant manner. In [13], a proposed wireless pulse oximeter prototype measures data gathered from patients, and the clinical analysis by a central unit assists and coordinates first-aid teams, updating information on clinical status and patient locations.

Services' provision is an attractive and important part of telemedicine that acts in the treatment process of patients. Studies of [14, 15] focus on supporting an alert emergency service generated when patients' vital signals change to an abnormal level to notify emergency medical teams and caregivers. Studies of [16, 17] present several services to patients, such as recommendations, tips, drug prescriptions, and tele-health consultation. The study of [18] presented a system to promote emergency treatments and confirmed the necessity of a cloud computing system for emergency rural health to mitigate deaths occurring due to time delays during patient transportation and a shortage of appropriate and timely first-aid. Furthermore, [19] provided healthcare services on-the-fly by vehicles in the case of patients traveling. The study of [20] presented first-aid operations and services that can be provided while the patient is in an ambulance. The study of [21] proposed a novel tele-health elderly healthcare service that connects remote physical therapists to seniors at homes by providing verbal, auditory, and visual cues to support correct exercise movements.

### 2.3 Tier2 (mHealth)

The category of mHealth can be divided into three areas as follows:

1. Treatment Support and Diseases Surveillance:

This area focuses on observing, predicting, and minimizing harm caused by outbreaks, epidemics, and pandemics, enhancing knowledge about contributing factors. Studies in this realm support patients in monitoring and managing body temperature, blood pressure, chronic diseases, and heart rate to obtain services from Tier 3 (server side) through mHealth. In [22], a Mobile Machine Learning Model for Monitoring Cardiovascular Diseases (M4CVD) was presented, utilizing a clinical database. [23] developed a monitoring system using the Arduino mega micro-system device, analyzing real-time signals, fusing multiple-sensor data, and transmitting information through an Xbee module. [24] introduced MobiPatterns, a mobile monitoring app continuously monitoring diabetes patients via smartphones and biometric devices. [25] presented a diabetic mobile app providing proper services based on low-level invasive impact technologies and new process models for integrating software components. [26] introduced "Jeev software app" for tracking vaccination coverage of children in rural communities. [27] presented a Mo-Buzz system using social media for preventing dengue in Sri Lanka and Southeast Asian regions. [28] presented a treatment mechanism to support major depression and provide personalized daily interactive sessions based on patients' history data, clinical requirements, and current responses. [29] developed a coaching approach known as personal coaching systems, using body sensors integrated with smart reasoning and context-aware feedback to support patients' healthy behavior. [30] introduced a general approach to assist patients' management with acute coronary syndrome, building a data-driven platform for an urgent Decision Support System for ambulances and emergency medical services.

2. Triage over mHealth:

Studies in this area are classified into two directions: triage-based disaster casualties and incidents, and triage-based home monitoring. [31] 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, transferring these signs to a medical record server in hospitals, and clustering into three levels (major, delayed, and minor). The AUDIME project approach in [32] evaluated the social acceptance and usability of smart and wearable devices in the context of managing Mass Casualty Incidents (MCIs). [33] proposed an automatic and intelligent self-tagging methodology for patients in MCIs using body sensor networks. [34] presented a solution to enhance the management of MCIs through the combination of a mobile device and a sensor-based platform, adopting the START method. [35] proposed a platform for a body-worn vital sign monitor to enhance medical resource allocation in disaster environments. [36] introduced a framework called multi-source healthcare architecture (MSHA) for developing telemonitoring systems, supporting remote triage and prioritizing patients with heart chronic diseases in Tiers 1, 2, and 3.

3. Network Failure between Tier 2 and Tier 3:

The study by [37] presented a prototype of Wireless Personal Area Network (WPAN) technology to track pilgrims in case of disasters, enabling communication even in tower-less areas using the ZigBee method. [38] considered an mHealth system for a tsunami-stricken disaster scenario, using D2D and LTE-direct technologies to restore lost communication links in infrastructure-less mobile/wireless ad hoc networks. [39] investigated an approach to improve communication reliabilities in patient monitoring, proposing power management protocols and a framework for leveraging mobile ad-hoc networks.

The study by [40] presented a temporary (ad hoc) wireless network for the technical feasibility of medical alarm dissemination in urban environments by mobile devices in case of infrastructure-based communication network failure or congestion.

## 3. GAP ANALYSIS

As the analyses of research in the literature review, failure in any part of telemedicine architecture will cause a significant impact on the overall system and adjacent customers of healthcare services.

In wearable medical sensor (Tier 1), the major problem with control congestion area is the network failure; it is not possible to completely avoided congestions for any network. Moreover, sensors characteristics may result in partial or complete failure, which can degrade the performance or even destroy the stability of the overall system [41].

In Tier 3, scalability challenges place a substantial burden on telemedicine applications by increasing demands for healthcare services, which causes network congestion and server failures. 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. Telemedicine services are dependent on client-server architecture, and many factors make affect network congestion and server cascaded failure. These factors include loading or denial of service,…etc., which causes an interruption in the provision of healthcare services to patients in real time [42].

In Tier 2 (mHealth), all studies in these areas presented various healthcare systems and applications which are completely controlled from the server side. A few studies 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. Although ad hoc-based architecture facilitates fast deployment when encountering a dynamic environment, such as medical emergency care response, or at a disaster site, however, the efficient QoS provisioning for mobile ad hoc networks is a challenging task, especially for different types of traffic [43]. These studies 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. 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.

In conclusion, none of the studies in literature considered a fault-tolerant framework when various failures occurred in the telemedicine architecture. Studies that investigated service delivery through mHealth still experience challenges in cases of network failure at Tier 3 or medical centre failures (Tier 3). Any disruption to a system of the telemedicine architecture can cause link outage, which potentially leads to severe consequences, 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 with the abovementioned problems has still not been issued yet. mHealth can address these failures to ensure continuous healthcare services provision as a recommended solution. Several relevant studies have posited that mHealth can solve the problems mentioned above and can provide services even in cases of network or medical centre failures..

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## 4. METHODOLOGY

The research methodology for the real-time IoT mHealth framework is divided into three phases, with a focus on identifying decision matrices, patients with chronic heart disease (CHD), and distributed hospitals.

Phase I: Identification of Decision Matrix (DM)

1. Identify the Targeted Tier within the Telemedicine Architecture:

- Tier 2 is the targeted tier for the proposed framework.
- Requirements include accurate healthcare framework by alarming patients in case of failure, detecting triage emergency levels, and establishing centralized IoT connections with distributed hospital servers during Tier 3 failures.
- Service weighting involves assigning specific weights to healthcare services within packages and Telemedicine Architecture Hierarchy (TAH) for evaluation by experts.
- Hospitals are ranked based on available services and TAH, prioritizing them in a queue.

2. Identification of Patients with Chronic Heart Disease (CHD) and Dataset:

- Patients with CHD undergoing remote home monitoring are identified.
- Three sensors (ECG, SpO2, blood pressure) and text data (complaints) are utilized for monitoring.
- Text data is used as a medical source for four yes/no questions.

3. Propose Three-Level Localization Triage (3LLT) for Triage and Detect Tier 1 Failures:

- Introduce a new Multi-Sensor Fusion Triage Algorithm (3LLT) for the telemedicine architecture.
- Data from Tier 1 is transmitted to Tier 2, allowing mHealth to detect Tier 1 failures and alarm patients.
- The algorithm determines the patient's emergency level, resulting triage level, healthcare service packages, and alarms.
- Three triage levels (Risk, Urgent, Sick) are identified based on a range of numbers (0 to 100) from sensor and text data, using the evidence theory method.

4. Identification of Distributed Hospitals:

- Select 12 hospitals as a proof of concept for testing the framework.
- These hospitals represent alternatives in the Decision Matrix (DM).

## 5. PROPOSE DM in MHEALTH

- Develop a DM based on the crossover of healthcare services package/TAH and hospitals list.
- Three decision matrices are proposed for ranking the 12 hospitals.
- The 3LLT algorithm is used to measure the triage level based on patient vital signs received from Tier 1.
- The output identifies the final triage level linked with a compatible healthcare services package.
- The framework then determines the DM according to the selected package, and requests are sent to hospitals to obtain data representing services based on IoT parameters.

This methodology phase outlines a comprehensive approach to the real-time IoT mHealth framework, integrating decision matrices, patient identification, triage algorithms, and hospital evaluations.

Phase II: Hospital Selection based Multi Criterion Decision Making

Several useful techniques can be employed to address Multiple Criteria Decision Making (MCDM) problems in the real world. These methods assist decision-makers in organizing and solving problems, conducting analysis, ranking alternatives, and scoring them [44]. Consequently, the scoring of suitable alternatives should be performed. MCDM methods can tackle the scoring problem in hospital selection in real-time IoT mHealth. In any MCDM ranking, fundamental terms need to be defined; these terms include the decision or evaluation matrix (EM), where possible alternatives are scored (e.g., Hospital 1, Hospital 2, Hospital n), and criteria against which each alternative's performance is measured (e.g., healthcare services and Telemedicine Architecture Hierarchy - TAH). Certain processes, such as normalization, maximization of indicators, addition of weights, and other processes depending on the method, should be completed to rank the alternatives.

The literature has indicated that Analytic Hierarchy Process (AHP), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods are suitable for selection problems, especially for supporting group decision-making and modeling uncertainty [45]. TOPSIS and VIKOR are functionally related to discrete alternative problems, but their chief shortcoming is the lack of provision for weight elicitation and judgment consistency checking [46]. VIKOR and TOPSIS are applicable for cases with numerous alternatives and criteria. These methods are also convenient to use when quantitative or objective data are given. However, the steps of VIKOR and TOPSIS are complex, leading to time-consuming ranking processes [47], which is a drawback considering time is crucial in the scope of this research (mHealth).

The major characteristic of the AHP method is the use of pair-wise comparisons, which are employed to compare alternatives with respect to various criteria and to estimate criteria weights. The AHP method, even with considerable variation among questionnaires used to create its input data, has successfully weighted criteria important for sustaining fisheries and resulted in alternative rankings similar to successful rankings in the past [48].

The AHP method is an effective technique to obtain the relative importance of various criteria with respect to the objective. AHP is used to set weights for objectives based on the preferences of stakeholders. It is significantly restricted by the capacity of humans for processing information; hence, the comparison ceiling is $7 \pm 2$. From this viewpoint, AHP alleviates the requirement for paired comparisons, but its capacity limitation might not significantly dominate this process.

AHP can also be used to rank alternatives. The method is convenient to use when quantitative or objective data are given and does not require significant amounts of time in the ranking process because the weights are already prepared from pair-wise comparisons. This is an important factor in ranking alternatives [49].

In conclusion, to provide healthcare services using mHealth, the AHP method will be used to fully rank hospitals, where each hospital has multi-services and TAH. In the first stage, AHP is recommended to set weights for the evaluation criteria (healthcare services and TAH) based on experts' judgments. In the second stage, AHP is recommended for ranking alternatives (hospitals) based on experts' judgments.

Phase III: Validation Process:

The validation process for the IoT mHealth framework will be conducted objectively. The ranking results of hospitals will be divided into four equal groups [50]. To ensure a systematic ranking of hospital selection, Mean ± Standard Deviation (statistical methods) is adopted based on hospital datasets. The ranking results are presented as mean ± standard deviation for each group. Each group consists of three hospitals (an equal number) selected based on the scoring values from the ranking results. According to the systematic ranking results, the first group should be statistically proven to be the highest among all groups. A value of 1 is assigned for each valid process, and 0 is assigned to invalid ones. In conclusion, the first group should be the best among the four groups, the second group should be the second-best, the third group should be the third-best, and the fourth group should be the least favorable among the others.

## 6. CONCLUSION

In conclusion, the proposed IoT mHealth framework serves as a crucial tool to enhance patients' confidence in the healthcare system by ensuring continuous healthcare service provision, even in the face of various failures within the telemedicine environment. This framework contributes significantly to the improvement of health monitoring for Chronic Heart Disease conditions, offering an efficient and cost-effective patient diagnosis system. The emphasis on delivering distinctive quality care aligns with the demands of modern lifestyles, allowing patients to maintain their independence within a normal living environment. Furthermore, the framework plays a pivotal role in fortifying the health system across distributed hospitals, thereby promoting dynamic processes and improving overall efficiency. It facilitates a comprehensive understanding of multi-team systems, fostering collaboration among healthcare professionals from various departments. This collaborative approach creates a climate for teamwork, ultimately enhancing patient outcomes. In its final and crucial role, the IoT mHealth framework provides valuable decision-making support for medical teams. Particularly, it streamlines the process of hospital selection, offering timely support for doctors and other medical staff. This not only optimizes resource allocation but also contributes to improved patient care, marking a significant stride in the advancement of healthcare services.

### Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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