Architecture of Wide Area Health Monitoring System

Xiaohan Liu[1,2](✉), Talatu Suri[3], Xiaoyun Zhao[4], Shilong Zhang[1,2], Ou Li[1,2], Yi Yang[1,2], Xiaochao Shi[5], Ping Liang[2], and Kuangyang Shu[1]

[1] CASET Quzhou Research Institute Co. Ltd., Quzhou, China
xhliu@giet.ac.cn
[2] Guangzhou Electronic Technology Co. Ltd., Chinese Academy of Sciences, Guangzhou, China
[3] Minzu University of China, Beijing, China
[4] Tianjin Chest Hospital, Tianjin, China
[5] PLA Strategic Support Force Characteristic Medical Center, Beijing, China

Abstract. Wearable health monitoring system has significant progress with the development of Internet of Things (IOT) technologies. In this manuscript, we discuss the collaborative architecture for distributed wide area health monitoring system. Heterogeneous communication, system modularization, and edge computing are three important aspects for the architecture. A real-world system has been developed, which includes three components: wearable sensor, wireless sensor network, and edge computing terminal, and we performed a series of experiments. We also discuss the collaborative mechanism for heterogeneous and homogeneous health monitoring systems in complex emergency environment.

Keywords: Health Monitoring · Distributed System · Internet of Things · Edge Computing · Collaborative System

1 Introduction

Wearable health monitoring technology has significant progress with the development of information, computing, and communication technologies in the past 20 years. Internet of Things (IOT), 5G/B5G communication, edge computing, satellite constellation internet, Artificial Intelligence (AI) provide more intelligent and rapid support for wearable health monitoring in wide area field environment [1–5].

Especially, health monitoring in extreme or natural disaster environment is important for both victims and rescue workers [6–11]. In wide area environment, we often apply heterogenous and independent information and communication systems at the meantime, the interoperability and scalability problems often make the health monitoring process inefficient and costly.

S. Wang (Ed.): IoTCare 2022, LNICST 501, pp. 289–298, 2023.
https://doi.org/10.1007/978-3-031-33545-7_20

In this manuscript, we discuss the architecture for wide area health monitoring system, as is shown in Fig. 1. We concern three aspects:

(1) Heterogeneous communication: cellular communication, such as LTE, NB-IOT, and 5G are widely applied in urban environment; while Wireless Sensor Networks (WSN), Low Power Wide Area Network (LPWAN), and satellite communication could be applied in rural areas;
(2) System modularization: in complex environment, modular system using open standards could provide better compatibility. Relative open standards such as OGC Sensor Web, Linux EdgeX Foundry, IEEE 1888, oneM2M are well discussed these years;
(3) Edge computing: we perform health data analysis and statistics, and system configuration in the system edge.

This paper is organized as follows: in Sect. 2, we discuss wide area health monitoring system architecture; Sect. 3 introduces a real-world system setup and experiments, and we discuss the collaborative mechanism for heterogeneous and homogeneous systems; in Sect. 4, we introduce the outcomes and discuss important topics on on-going research.

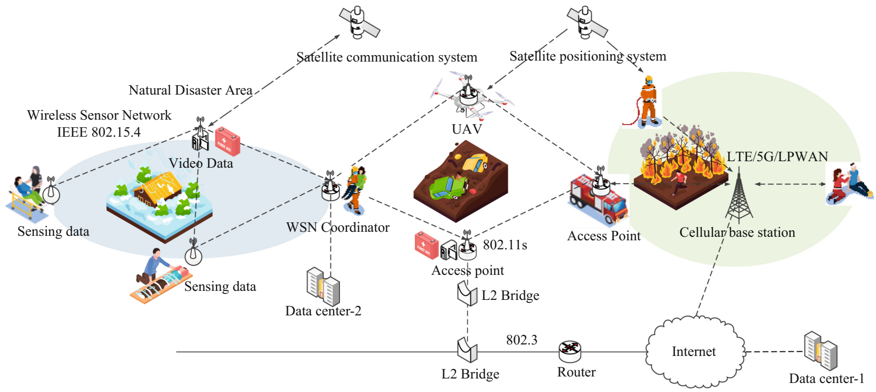


Fig. 1. Wide Area Health Monitoring System

2 System Architecture

For centralized health monitoring system, monitoring terminal such as smart watch, smart wrist band, or a WSN coordinator, transmits data to mobile phone or cloud server. For distributed system, gateway node collects and transmits data to certified cloud server using open protocols. Figure 1 shows a hybrid health monitoring system, which has a centralized system data center (Data center-1), and a distributed system data center (Data center-2).

Figure 2 shows the collaborate architecture for wide area health monitoring system. The gateway collects data from multi nodes through various of capillary communications, such as LPWAN, IEEE 802.15.4 WSN, IEEE 802.11s mesh network, or satellite network, and then communicates with the edge/cloud server through cellular or capillary communication. The system collaboration platform includes registration component, centralized configuration component, cooperation component, computing component, visualization component, etc. Various of applications, such as health, rescue, training, and management, connect with the platform and acquire data from proper cloud server and data center.

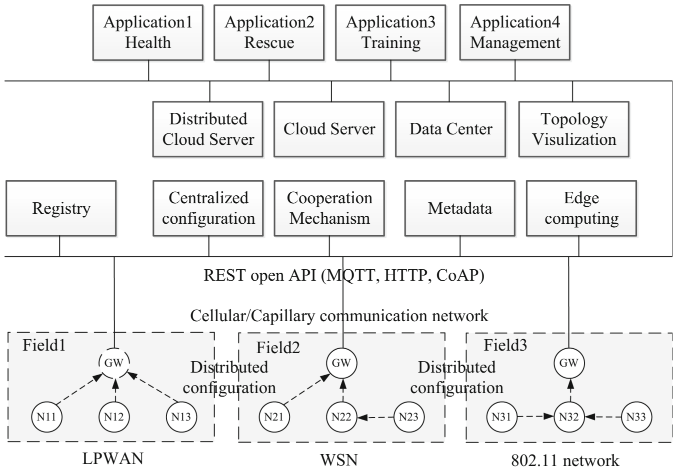


Fig. 2. System architecture

Figure 3 shows the system's working process:

Registration: the sensing node, gateway, edge/cloud server, and application unit first register ID, content information, and metadata to the collaboration platform;

Centralized configuration: the cooperation component implements resource allocation and collaborative computing on the base of registered application, then the centralized configuration component transmits configuration information to the registered unit, and each unit configures its parameters such as data model or edge/cloud server addresses;

Computing and application: the sensing node, gateway, and edge/cloud server calculate and transmit the effective data using configured model/algorithm, and then the applications acquire data from the edge/cloud servers.

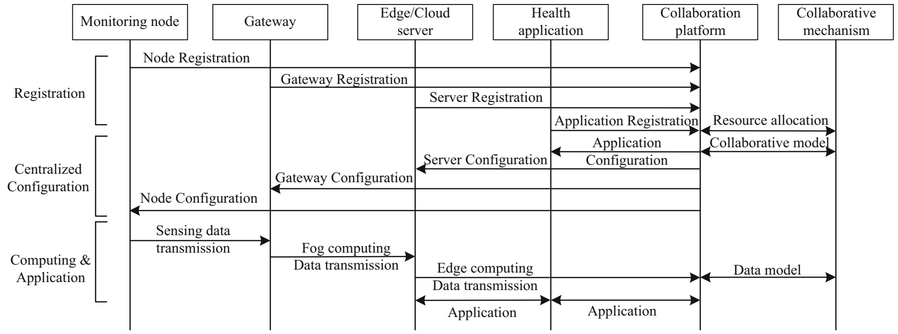


Fig. 3. Health monitoring system's working process

3 System Implementation

A. System Composition and Working Process

A health monitoring system composition is shown in Fig. 4. The system hardware composition is shown in Fig. 5.

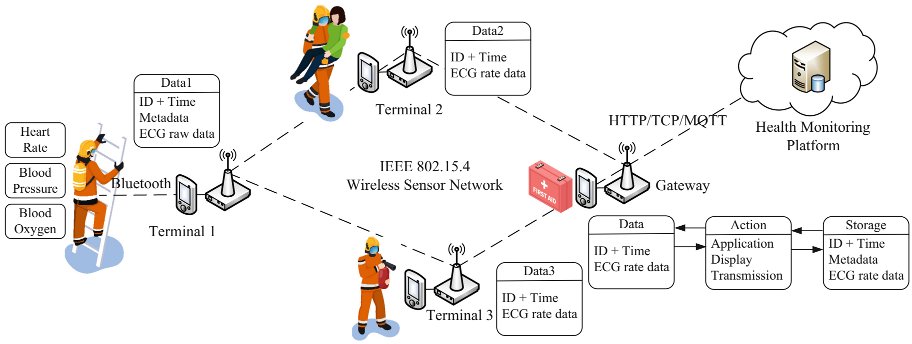


Fig. 4. System composition

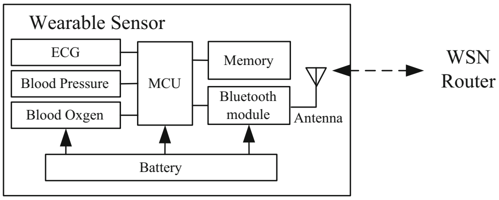
The health monitoring process includes 4 steps:

Step 1: we apply wearable sensors to acquire ECG, blood pressure, and blood oxygen raw data. User ID, time, metadata, and monitoring raw data are then sent to fog system using Bluetooth communication;

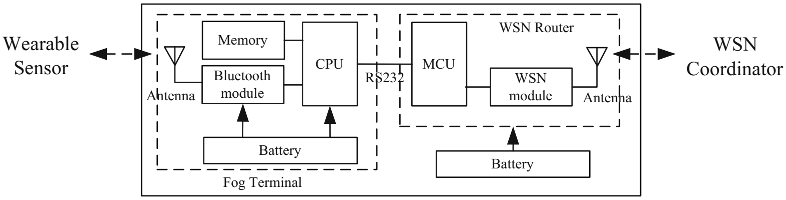
Step 2: a fog terminal implements data processing, display, transmission, and storage functions. The effective data such as heart rate are calculated from the ECG raw data, and data set *D(ID, time, metadata, ECG rate)* is then stored in the fog terminal memory;

Step 3: the fog terminal connects with a WSN router node, and multi nodes' health data (Data1, Data2, and Data3) are sent to a WSN coordinator (gateway) using IEEE 802.15.4 or IEEE 802.11s mesh communication;

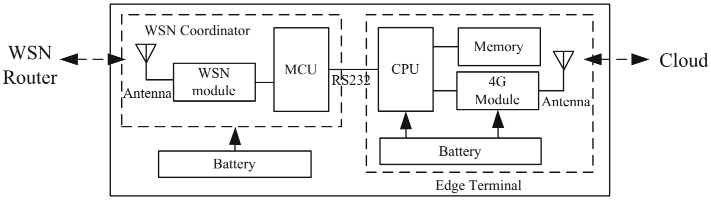
Step 4: the WSN coordinator/gateway node connects with an edge terminal, which implement edge computing, storage and application functions. The edge terminal interacts with collaboration cloud platform using HTTP, TCP, or MQTT internet protocols.



(a) Wearable Sensor terminal



(b) Fog system



(c) Edge system

Fig. 5. System hardware composition

Table 1. Specification of a Health Monitoring System

Item	Specification
Wearable Sensor	Oranger Mi-Rhythm ECG sensor ECG range: 30 bpm–300 bpm; Channe l:1; Size: 45 * 25 * 7 mm; Weight: 10 g ± 1 g
Fog Terminal	CPU: Hisilicon Kirin 710F; OS: Harmony; Maximum frequency: 2.2 GHz; RAM: 4 GB; ROM: 64 GB
WSN module	Digi XBee wireless module Frequency: 900 MHz; Data Rate: 200 kbps
Edge Terminal	CPU: Hisilicon Kirin 659; OS: Harmony; Maximum frequency: 1.7 GHz; RAM: 4 GB; ROM: 64 GB

B. System Implementation

We set up a real-world system, and the system specification is shown in Table 1. We use Oranger Mi-Rhythm ECG sensor to monitor 30–300 bps ECG data; we develop series of software using Harmony OS in fog and edge terminal; we use Digi Xbee wireless module to implement the IEEE 802.15.4 WSN router and coordinator.

Figure 6 (right) shows the fog terminal and software user interface; Fig. 6 (left) shows the acquired ECG raw data and calculated heart rate data.

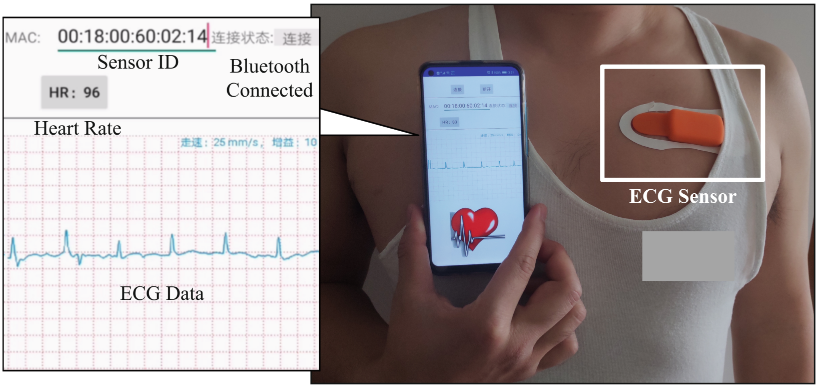


Fig. 6. Fog Terminal and sample ECG data

The prototype edge system is shown in Fig. 7, includes an edge terminal and a WSN coordinator. The edge terminal software user interface includes the comparison of data from multi terminals (fog terminal 1 and fog terminal 2), and data analysis for each terminal.

Figure 8 (a) shows the working process of the WSN router nodes. The router node refresh the network topology on the base of received configuration and link information packet, and transmit both link data and sensing data to the coordinator;

Figure 8 (b) shows the working process of the WSN coordinator. The coordinator refreshes the WSN network topology, and sends configuration and link information packets to all WSN router nodes, then transmits received sensing data to the edge terminal.

C. Heterogeneous Systems' Collaboration

On the base of the proposed architecture and developed single system, we design the collaboration mechanism for multi domain systems, including homogeneous system, heterogeneous system, and general collaborative system.

(1) Homogeneous systems' collaboration: the monitoring terminal and gateway nodes adopt unified open standards for data sensing and transmission, and the nodes could interact data with each other directly. The user could design various of collaboration algorithms according to the application requirements.

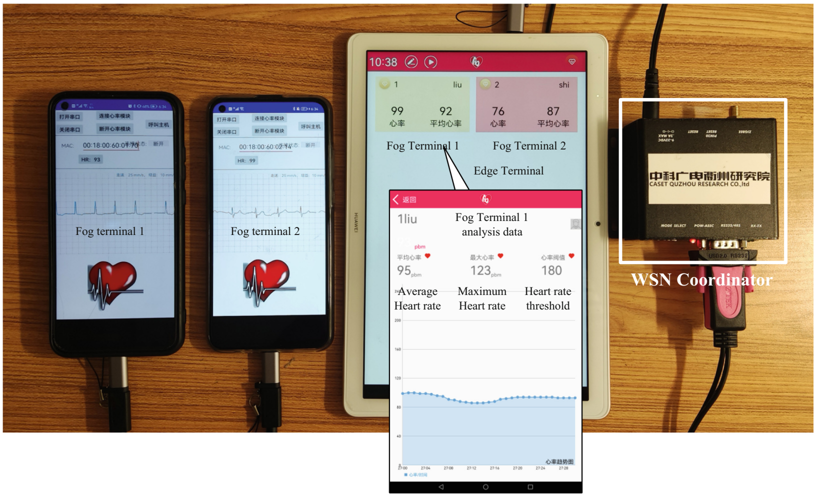


Fig. 7. Edge terminal and sample heart rate data

(2) Heterogeneous systems' collaboration: the gateway nodes adopt different standards for data sensing and transmission, so we need to develop software or hardware middleware in the north direction of the gateway node. And the gateway node could interact with other system using the middleware.

(3) General collaborative system: in a general system, homogeneous and heterogeneous systems from multi domain collaborate with each other for complex task. The hierarchical structure is shown in Fig. 9, and we concern the three types system collaboration.

There are three kinds of computing servers: the edge collaboration server implements the control and configuration function; the data server implements the data interaction function; the general emergency server implements the application function. The edge collaborative server transmits configuration information to registered gateway or middleware nodes, which compose systems' control chain; each gateway or middleware node interact with the cloud/edge data server, and compose systems' data chain.

The homogeneous system A and C's gateway nodes, heterogeneous system B's middleware node perform data interaction on the base of the configuration information. The unregistered heterogeneous system D's middleware node, and homogeneous system E's gateway node, interact with system C's gateway node, and join the inter systems' data chain. The sub-layer terminal nodes are managed by the gateway node.

We concern three parameters for the collaborative data chain: location of the disaster area and people, location of the gateway node of homogeneous system or the middleware node of heterogeneous system, and network connectivity condition. The network connectivity status is confirmed by the network topology update module. During one clock cycle, the gateway or middleware node broadcasts "Hello message", which includes ID and node's location. The receiver sends back an "ACK message", which includes receiver's ID and location, and after handshake we confirm the sender and receiver have neighborhood relationship, then the network topology is updated. For a new registered

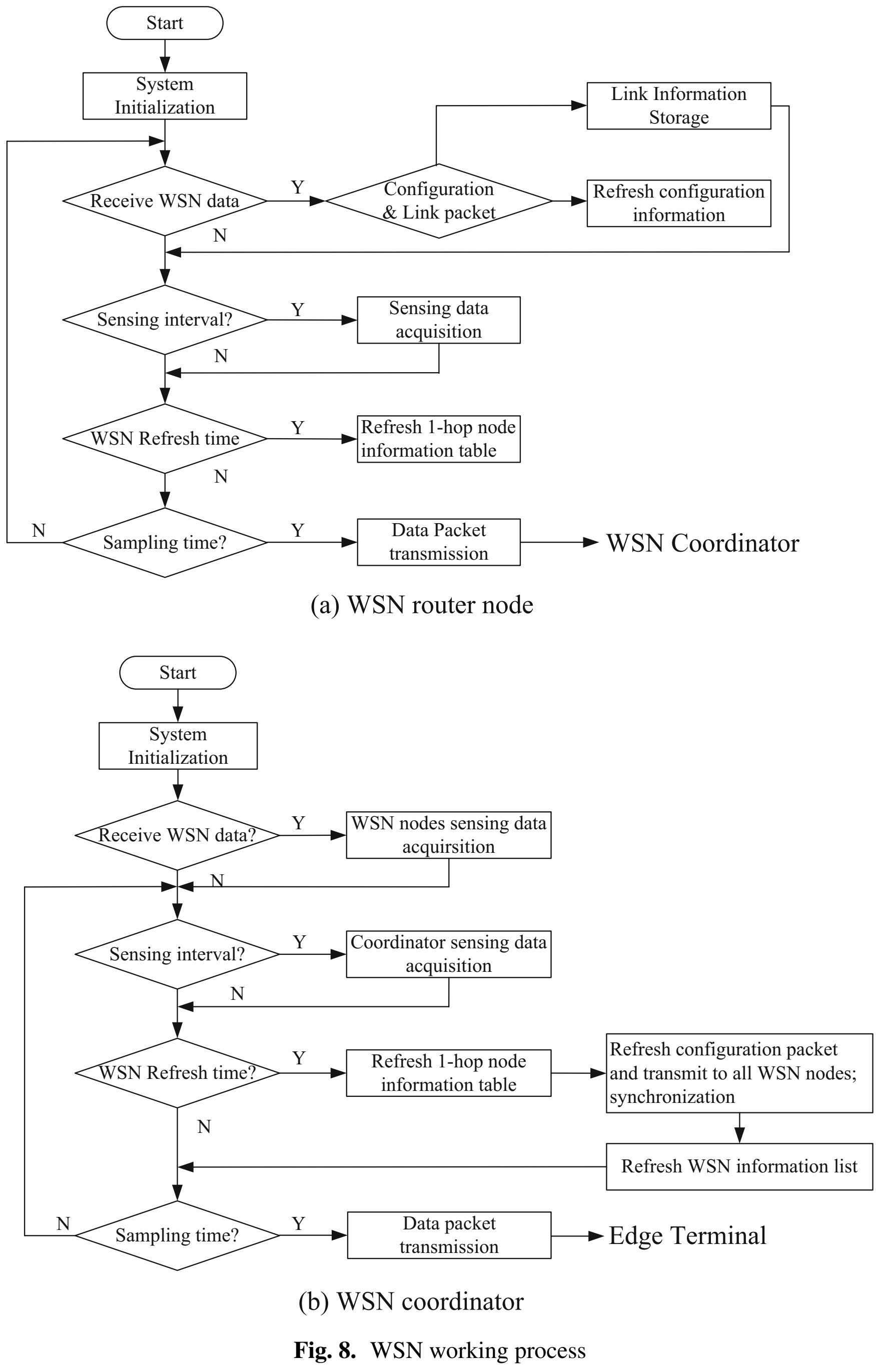


Fig. 8. WSN working process

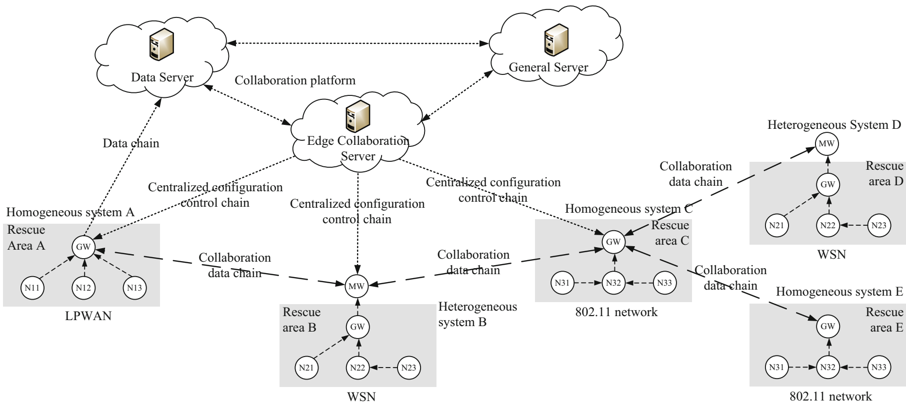


Fig. 9. Hierarchical structure of collaboration systems

gateway or middleware node, the destination is affected by disaster area and people's location, and neighbor node's location. The location parameters "pull" the node periodically. When all the nodes come into a "stable status" according to the application requirement, we consider that the system has completed the emergency task.

4 Discussion

In the proposed system architecture, each system's configuration could be centralized informed from the collaboration platform according to the application requirements, and each system proceeds the configuration in a distributed manner. Therefore the architecture has advantages in at least two following aspects:

(1) Scalability: the sensing and computing algorithm could be modularized, and heterogenous and homogeneous systems could work together using the architecture and open standards. Sensing units could update algorithms/models for different applications with the support of middleware.
(2) Resilient system: in wide area environment, when a sub-system is destroyed or moved, the applications could delete or mark the sub-system records in the registration list easily. Since the communication status is unpredictable, Delay Tolerant Network (DTN) mode command, and routing algorithms could be configured from the collaboration platform to the sub-system.

Currently, only ECG sensor is applied in the system, more sensors will be applied in future development. In Sect. 3 (a)–(b), we introduce the development of an "end-to-edge" health monitoring system. Based on the mechanism introduced in Sect. 3 (c), we are developing the "edge-to-Cloud" collaboration system using docker technology, and the micro services include: data receiving interface service, registration service, collaboration model service, health data output API interface service, system topology service, etc. A sample output data set could be described as *Data (ID, Type, No. of terminals, Communication radius, area width, area length, No. of monitored people, people's location).*

5 Conclusions

In this manuscript, we propose a collaborative architecture for distributed wide area health monitoring system, and we concern 3 aspects: heterogeneous communication, system modularization and open standards, and edge computing. A real-world ECG monitoring system has been implemented, which includes ECG sensor, Wireless Sensor Networks, and fog/edge terminals. An "End-to-edge" collaboration mechanism and a series of experiments have been performed. Also we discuss the "edge-to-cloud" collaboration mechanism and implementation for heterogeneous and homogeneous systems in complex wide area environment.

The proposed architecture and real-world system implementation provide guidelines for wide area data sensing and communication system construction in IOT and 5G/B5G era. We are focusing on general integrated emergency sensing system on on-going research.

Acknowledgment. This research is supported by Science and Technology Project grant of Quzhou city (No. 2020K13).

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