Smart Hospitals and IoT Sensors: The Healthcare Future

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Hospitals are already adopting sensor devices of many types to monitor medical processes. Patients and medical staff can now wear sensors that provide movement and health conditions information in near-real time. Additionally, many sensors can monitor physical settings generating information about the environment and medical equipment. This set of sensors has the potential to provide information to support decision-making processes and medical data analytics. Internet of Things (IoT) is spreading among several areas, paving the way to a new industrial revolution.

healthcare 4.0 internet of things sensors

1. Introduction

Healthcare 4.0 is coming [1][2]. Hospitals are already adopting sensor devices of many types to monitor medical processes. Patients and medical staff can now wear sensors that provide movement and health conditions information in near-real time. Additionally, many sensors can monitor physical settings generating information about the environment and medical equipment. This set of sensors has the potential to provide information to support decision-making processes and medical data analytics [1][3]. Currently, the analysis of data from medical settings takes place reactively [4]. Medical staff take action to tackle problems with the patients' health only when critical situations occur. A physician decides the actions to take based solely on traditional examination data from the patient.

This situation exemplifies the reactiveness of medical processes taking action only after an emergency. Further, this process is individual for each patient. It does not contain a centralized analysis of the medical environment. Ideally, decision making should employ a global analysis of the medical processes, generated in real time using data from all patients and the medical environment. In this context, patient remote health monitoring becomes crucial [5]. That would allow proactive data analysis to predict critical situations before they occur.

On top of such infrastructures, it is feasible to employ artificial intelligence technologies [2][5][6]. Among many strategies, three stand out: (*i*) data prediction [7]; (*ii*) pattern recognition [8]; and (*iii*) data correlation [9]. Data prediction allows to forecast measurements and situations, anticipating problems and the required countermeasures. In turn, pattern recognition offers strategies to identify situations that have already occurred in the past. Lastly, data correlation combines information from multiple parameters to identify the source of specific situations. For instance, data correlation strategies are currently employed for ICU patients with Coronavirus Disease 2019 (COVID-19) to identify the relation between many indicators [10].

Figure 1 presents an overview of future medical processes. Internet of Things (IoT) is spreading among several areas, paving the way to a new industrial revolution [6][11]. In hospitals, this is not different [4]. This context encompasses the numerous sensor devices scattered all over the hospital setting generating information from various assets, including the patient and the medical team. Currently, artificial intelligence applications emerge to handle an increasing data volume. It supports the medical team by providing information to help them perceive dangerous situations and patient condition deterioration. Medical processes are highly critical, and errors or delays in handling critical situations may harm the patient and even lead to death. With a wide variety of data provided by IoT technology, centralized systems provide a global analysis of data from patients improving healthcare services.

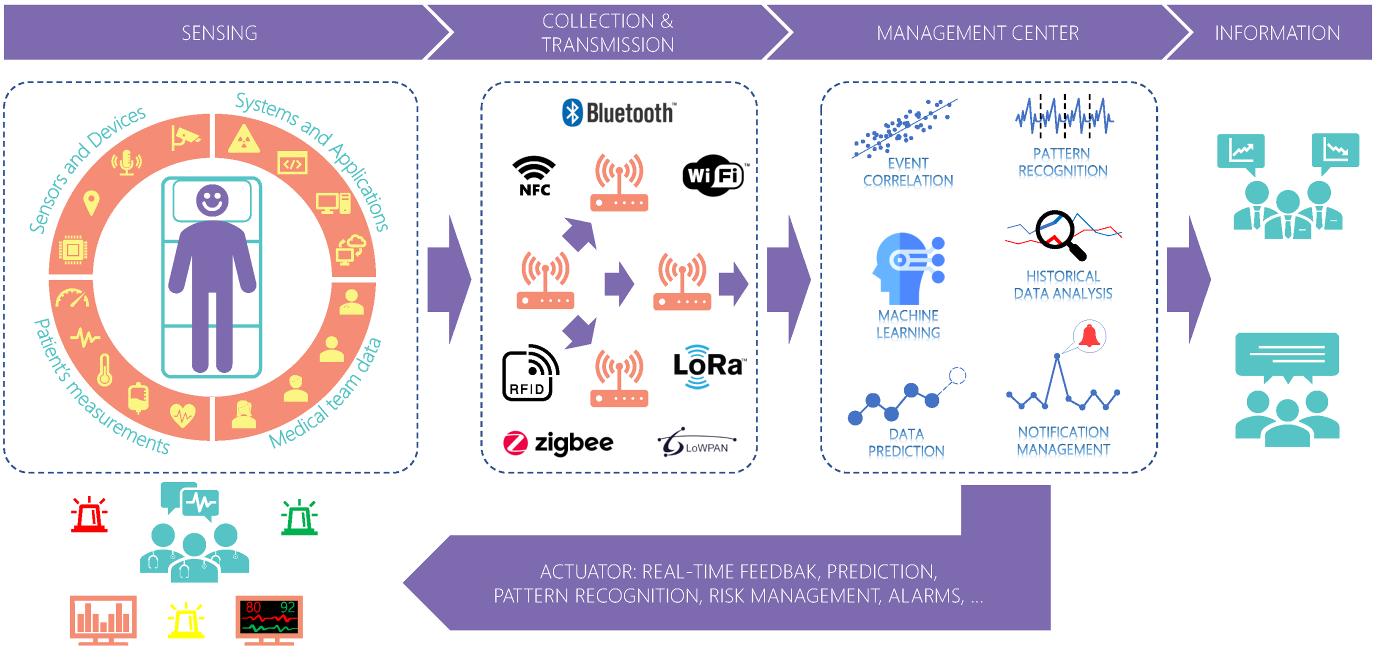

Figure 1. Real-time data acquisition, analysis, and feedback in healthcare. Sensors close to the patient and medical staff generate numerous information collected and transmitted for remote processing. Several applications can profit from this information for further analysis and real-time feedback to actuators.

Although positive, centralized systems suffer from scalability problems which may increase the delay in data transmission. Scalability is the ability of a system to maintain its performance and quality of service (QoS) regardless of the input workload and internal processing [12]. Centralized systems concentrate data processing at a single point. As the number of sensors and applications connected increases, the system can lose performance due to network overload. That would cause instabilities in the data flow to different systems, which can be critical depending on the application. Therefore, a sensor data middleware for medical settings must provide QoS to the applications.

2. Related Work of Smart Hospitals and IoT Sensors

Table 1 summarizes the main articles published in the last four years and their goal and QoS strategy. Among different QoS methods, studies focus mainly on four common strategies: (*i*) scheduling protocols [13][14]; (*ii*) data prioritization [13][14][15][16][17][18][19][20]; (*iii*) routing protocols [20][21][22][23][24][25]; (*iv*) resource management [14][19]. Studies have examined the use of data prioritization to reduce transmission time. This strategy encompasses distinct classes for each data type, prioritizing high-priority packets. Some approaches use admission control algorithms to ensure a network's quality. Thus, an algorithm checks the current network state and estimates the future state to decide whether to allow new connections. Cloud environments commonly use resource elasticity, and some researchers use it as a way to provide QoS. During overloaded conditions, such strategies use VM allocation and migration strategies to enhance the performance of some modules. Finally, some researchers also employ routing and scheduling protocols to improve the performance of networks and reduce transmission delays. The routing algorithms determine the most optimal route for transmitting data based on network conditions. On the other hand, scheduling protocols control the time slot assignment for each data transmission and their order based on the amount and type of data.

Table 1. Summary of the research and QoS strategies in healthcare solutions.

Paper	Year	Real Time	QoS Strategy	Description
[26]	2019	✓	Video smoothing	QoS control algorithm to 5G telemedicine.
[16]	2019		Data prioritization	Slicing framework for eHealth media applications over 5G networks.
[17]	2019		Service differentiation, data categorization and prioritization	Medical grade QoS solution.
[13]	2019	✓	Service differentiation, routing protocol	QoS-aware multipath algorithm for medical data transmission in a SDN.
[27]	2019		Clock synchronization	Protocol for QoS and energy efficiency in WBAN.
[18]	2019	✓	Traffic differentiation	IoT architecture for data access.
[19]	2020	✓	Data prioritization and data rate adaptation	IoT architecture for data access.
[23]	2020	✓	Channel selection	Dynamic channel and superframe selection scheme in IEEE 802.15.6 WBANs to avoid interference.
[24]	2020	✓	Routing protocol	Strategy for selecting an optimal end-to-end route in WBAN.
[25]	2020		Routing protocol	Routing protocol for WBAN medical data.
[20]	2020		Routing protocol and data prioritization	WBAN architecture.

Paper	Year	Real Time	QoS Strategy	Description
[21]	2021		Routing protocol	QoS optimization in IoMT remote health monitoring.
[22]	2021		Routing protocol	Routing algorithm for WBAN health monitoring.
[14]	2021		Data prioritization, energy control, packet scheduling protocol and data rate adaptation	Patient monitoring using WBAN.
[15]	2021	✓	Data prioritization	OpenFlow traffic shaping in the Fog using SDN for e-health services.
[28]	2022	✓	Dynamic resource allocation	Private cloud with dynamic resource management for health services.
[29]	2022	✓	Communication protocol	IoT architecture employing edge and fog computing for health services.

[14][20][22][23][24][25][27]. A WBAN comprises a private network of connected sensors transmitting data to a master node that relays the information to upper network layers. Energy consumption and interference are the main problems studies seek to resolve by employing routing protocols and channel selection strategies. Their primary focus is to improve network transmission from the WBAN to the upper network layers. Such strategies can solve the internal problems of WBANs; however, they do not focus on multiple WBANs simultaneously. In other words, initiatives focusing on WBAN propose QoS strategies only within the WBAN boundaries and not the higher level which consumes data. Recent advances employ fog computing as a new solution to bridge the gap between the sensors and the cloud to decrease response time. Some strategies employ fog to provide data processing closer to the sensors and, therefore, remove network hops needed to reach the cloud [28][29]. Despite its advantages, fog solutions still require data extraction and transmission from the sensors and the fog nodes. Depending on the infrastructure, the volume of data and the quality of the transmission channel can still impose restrictions and impact the QoS.

Within a hospital, there are many critical locations, such as operating rooms, in which a system can provide helpful data from patients and physicians. Most strategies focus on remote health sites, like nursing homes, and only WBANs for patient health monitoring. In addition, a healthcare system has two main actors: the sensors at the hardware level, generating information, and the users at the application level, which consume and process data from the system. Strategies focus mainly on the first level to provide QoS in data transmission from the sensor to the network. Furthermore, although some initiatives present concerns regarding real time, they do not focus intensely on this issue. In general, solutions that focus on real time only consider improving time delay from priority packets or providing an architecture that supports real-time data transmissions.

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