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REVIEW

Survey on Monitoring and Quality Controlling of the Mobile Biosignal Delivery

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Abstract A Mobile Patient Monitoring System (MPMS) acquires patient's biosignals and transmits them using wireless network connection to the decision-making module or healthcare professional for the assessment of patient's condition. A variety of wireless network technologies such as wireless personal area networks (e.g., Bluetooth), mobile ad-hoc networks (MANET), and infrastructure-based networks (e.g., WLAN and cellular networks) are in practice for biosignals delivery. The wireless network quality-of-service (QoS) requirements of biosignals delivery are mainly specified in terms of required bandwidth, acceptable delay, and tolerable error rate. An important research challenge in the MPMS is how to satisfy QoS requirements of biosignals delivery in the environment characterized by patient mobility, deployment of multiple wireless network technologies, and variable QoS characteristics of the wireless networks. QoS requirements are mainly application specific, while available QoS is largely dependent on QoS provided by wireless network in use. QoS provisioning refers to providing support for improving QoS experience of networked applications. In resource poor conditions, application adaptation may also be required to make maximum use of available wireless network QoS. This survey paper presents a survey of recent developments in the area of QoS provisioning for MPMS. In particular, our contributions are as follows: (1) overview of wireless networks and network QoS requirements of biosignals delivery; (2) survey of wireless networks' QoS performance evaluation for the transmission of biosignals; and (3) survey of QoS provisioning mechanisms for biosignals delivery in MPMS. We also propose integrating end-to-end QoS monitoring and QoS provisioning strategies in a mobile patient monitoring system infrastructure to support optimal delivery of biosignals to the healthcare professionals.

Keywords Quality of service · Mobile patient monitoring system · Service differentiation · Cross-layer scheduling · QoS mapping · Vertical handover · Biosignals compression

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1 Introduction

The Information and Communication Technology, prevalently referred to as ICT, is revolutionizing daily living, communication and behavior of people with applications in almost every area of life. ICT in healthcare is also known as the Electronic Health (E-Health) which is a rapidly growing field in the intersection of medical informatics, public health, and business. Due to widespread adoption of mobile devices and ubiquitous availability of wireless networks, the healthcare services, and information delivery are undergoing transition from E-Health to Mobile Health (M-Health). M-Health refers to the application of mobile computing, wireless communications, and networked computing technologies to deliver or enhance diverse health services and information in which the patient movements are not restricted. The mobile patient monitoring is an emergent M-Health application that refers to the continuous or frequent measurements and analysis of the biosignals of a possibly moving patient remotely using the mobile computing, wireless communication, and networked computing technologies [1]. The term biosignals refers to various types of signals that quantify physiological processes of the living organisms. The common types of biosignals [2] are: (1) measurable using physical quantities, e.g., temperature or pressure; (2) measurable using electrical quantities, e.g., electrocardiogram (ECG) and heart rate variability (HRV); and (3) measurable using biochemical quantities, e.g., concentrations. A Mobile Patient Monitoring System (MPMS) acquires patient's biosignals and transmits them using wireless network connection to the decision-making module or healthcare professional for decision-making about patient's condition. The healthcare professionals use biosignals for properly diagnosing a disease, making a treatment decision and providing feedback to the patient.

The end-user of delivered biosignals is a healthcare professional and their requirements on the quality of biosignals received can be described in terms of the following: (1) Are the biosignals needed for decision-making are available? (2) Whether the biosignals data being received are of sufficient quality to make a decision? (3) If required, has the patient received feedback well in time to react? These requirements could be mapped onto the quality-of-service (QoS) requirements of biosignals delivery.

The QoS is widely considered as a performance of data delivery service offered by a network communication path. The QoS requirements are mainly characterized in terms of network connection availability, required bandwidth, acceptable delay, and tolerable error rate. The network communication can be supported by multiple network environments—such as RF, multi-hop ad-hoc, cellular, and WLAN. The QoS offered by wireless networks is variable—specifically, it is dependent on location, time, wireless network technology, and number of users simultaneously transmitting data. The typical network communication problems observed during the trials of MPMS are: fluctuation in bandwidth availability, delays in biosignals transmission, loss of network connectivity, and network coverage problems due to patient wandering out of range of the transmitter node [1, 3]. Hence, an important research challenge in the MPMS is how to satisfy QoS requirements of biosignals delivery in the environment characterized by patient mobility, deployment of multiple wireless network technologies, and variable QoS characteristics of the wireless networks.

This paper provides a survey of recent developments on QoS in telemedicine/E-Health applications. An overview of network QoS parameters for E-Health applications and network QoS requirements for delivery of most common biosignals is presented. Researchers have proposed multiple approaches for QoS provisioning in telemedicine applications for providing a better average QoS for biosignals delivery. This paper presents a summary of popular QoS provisioning approaches. We also include a survey of performance evaluation of ad-hoc and infrastructure-based wireless networks for the transmission of biosignals.

The remainder of this paper is organized as follows: Section II is a general introduction to mobile patient monitoring systems and QoS in telemedicine/e-health applications. Section III provides a survey of QoS performance evaluation exercises of wireless networks for the transmission of biosignals. Section IV presents a survey of QoS provisioning mechanisms and application adaptations for biosignals delivery in wireless networks. Conclusion and future work are presented in section V, where we emphasize on integrating QoS requirements, QoS monitoring and QoS provisioning strategies in a mobile patient monitoring system infrastructure to support optimal delivery of biosignals to the healthcare professionals.

2 Mobile Patient Monitoring Systems and QoS in E-Health Applications

Driven by technical advances and need to provide a better healthcare for growing number of patients, the present day healthcare system is undergoing a fundamental transformation from the conventional hospital-centered system to individual-centered system [4]. Mobile Patient Monitoring Systems (MPMS) that use miniature sensors to collect patient's biosignals and low-cost wireless networks for data transmission are playing a crucial role in this transformation. For example, the advances in MPMS now make it possible to detect epileptic seizures from changes in the cardiac rhythm round-the-clock [5]. Though presently MPMS are mainly considered to support healthcare processes, in near future, they will form an integrated part of the health system and will be accepted widely for specific tasks such as chronic disease monitoring [6]. In this section, we present a generic architecture of MPMS, wireless network technologies used for MPMS, and associated QoS concepts.

2.1 Generic Architecture of MPMS

According to the generic architecture of MPMS shown in Fig. 1, MPMS is a set comprising of Body Area Network (BAN) and Back-End System (BESys). The BAN is defined as a network of communicating devices worn on, around or within the body which is used to acquire health related data and to provide mobile health services to the patient. The BAN consists of a Mobile Base Unit (MBU) and other BAN devices such as sensors, actuators, and other

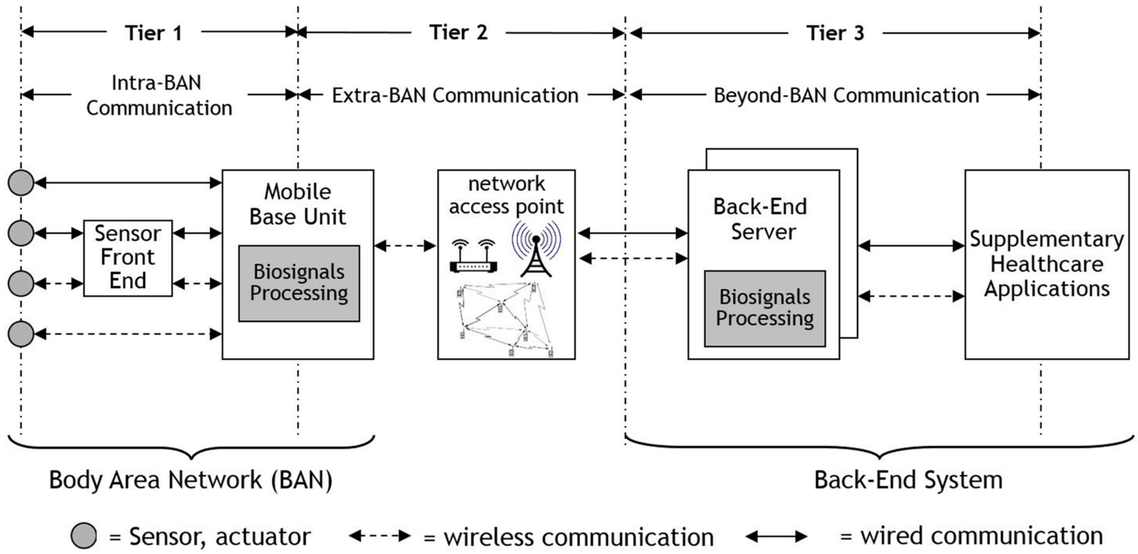

Fig. 1 Generic architecture of a mobile patient monitoring system

devices used for clinical purposes. The biosignals acquired from BAN sensors can be directly sent to the MBU or via Sensor-Front-End (SFE). The MBU functions as a communication gateway for transmitting biosignals to the BESys for processing and analysis. The BESys comprises of the back-end-server(s) and healthcare applications which make use of biosignals being received at these servers [1]. Within MPMS, the MBU and the back-end system communicate with each other using wireless network connection. The communication architecture of MPMS is divided into three tiers as follows [1, 7–12]:

- *Tier-1 (or intra-BAN) communication:* The tier-1 communication is between the BAN nodes and MBU and also among the BAN nodes themselves. This communication tier has a short range and it takes place around the human body. The sensor data rates differ widely according to sensor type. The sensors are usually equipped with small batteries and communicate using short-range wireless personal area network technologies such as Bluetooth, ZigBee, and IEEE 802.15.6.
- *Tier-2 (or extra-BAN) communication:* The tier-2 communication is between the MBU and the network access point/base station which is responsible to connect the BAN to the hospital network. The base station is equipped with a wireless communication interface to communicate with the MBU along with a long range communication capability (using wired or wireless connectivity) to transfer biosignals data to the back-end servers. The wireless networks used for tier-2 communication fall primarily into two categories: Mobile Ad hoc NETworks (MANET) and infrastructure-based networks (e.g., WLAN and cellular networks) [7]. In the MANET-based approach, multiple access points are deployed to help transmit biosignals information to medical professional. The use of access points is to form a mesh-like structure, which supports better patient's mobility and allows fast and flexible deployment of MPMS to respond during emergency situations. The infrastructure-based approach assumes an environment with limited space (e.g., home, office, and hospital) and makes use of the existing WLAN and/or cellular networks (2G, 3G, and 4G) for the transmission of biosignals. In this paper, we mainly focus on QoS provisioning in extra-BAN communication networks to ensure successful delivery of biosignals to BESys.
- *Tier-3 (or beyond-BAN) communication:* The communication between the network access point and back-end server using the Internet or the cloud network is referred as tier-3 communication. The back-end server consists of database that maintains patient's profile and biosignals data. According to medical requirements, the supplementary applications may access biosignals data as needed using the Internet. The supplementary applications are designed by taking into account patient-specific needs, e.g. an alarm could be triggered and doctor could be notified on detecting abnormal biosignal activity. An ambulance carrying a trauma patient may send patient's biosignals wirelessly to a team of doctors in the hospital, so that necessary arrangements could be made to respond to emergency. Cloud computing-based approaches [13, 14] are increasingly used for the storage of health data including biosignals and provide this data on demand to healthcare professionals. In these approaches, the healthcare tasks are processed on virtual machines and results are returned to healthcare

professionals. In some situations, the cloud may also host application servers.

2.2 QoS in E-Health Applications

The QoS is widely considered as a performance of data delivery service offered by a network communication path. This performance is measured in terms of QoS characteristics. A comprehensive survey of QoS in the mobile computing environment is presented in [15]. In [15], the QoS characteristics are classified into two groups: technology-based and user-based. Technology-based QoS characteristics describe the data delivery performance of a network, whereas the user-based QoS characteristics describe the quality of data delivery as perceived by the user. Table 1 summarizes these characteristics into seven main categories. We also consider power consumption of a sensor/device battery as one of the cost factors.

A comprehensive survey of M-Health applications from a wireless communication perspective is presented in [16]. A classification of sensor/video/medical data transmission is presented according to their criticality in three categories: low, medium, and high. It is noted that the QoS requirements of M-Health systems strongly depend on the application; however, low end-to-end delay is considered as the most stringent QoS requirement for real-time monitoring cases. A review on wireless patient monitoring using WBAN is presented in [17]. The QoS parameters considered are bandwidth, delay, packet loss, and link loss. As reported in [17], delay in medical applications should not exceed 125 ms, whereas bit error rates in the range of 10^{-3}–10^{-10} should be supported, depending on the application. Highest priority should be given to handling of alarm messages generated by a sensor device as they can be closely associated to urgent, life threatening conditions for the patient.

The E-health data are divided into three QoS classes in [18]. Class-A consists of emergency alarms, medical continuous data, and medical routine data with delay ranging from (0.1 to 0.3 ms). Class-B consists of non-medical continuous data with delay range 0.4; while Class C consists of other data like file transfer with higher delay requirements. In [19], it is evaluated the QoS requirements of some key medical applications. It is noted that packet delivery ratio, security, service latency, and jitter are crucial QoS parameters for M-health applications. In many cases, health monitoring information is prioritized based on the delay constraint, but in [20] medical applications are prioritized according to their medical urgency. The QoS parameters considered in [21] for sending medical data are bandwidth, delay, round-trip-time, and power consumption of a mobile device for sending biosignals data.

The International Telecommunication Union defines Quality of Experience (QoE) as the overall acceptability of an application or service as perceived subjectively by the end-user. The work reported in [17] argues that QoE depends on the QoS provided by underlying communication systems. It is noted that in remote surgeries relying upon long communication links, time delay would be a major constraint resulting in poor user perception (and thus lower QoE). A study addressing the topic of evaluating QoE for non-emergency remote patient monitoring services is reported in [22]. This study involves 26 users using a service based on a smartphone application for the measurement of vital signs via medical sensors. The results show a strong correlation between QoE and perceived effectiveness of the mobile interface, perceived ease of conducting a blood pressure measurement task, and user motivation for service usage.

Given these QoS categories, Table 2 compares the existing approaches with respect to QoS categories explicitly considered by them for biosignals data transmission. Most of the approaches consider that timeliness, bandwidth, and reliability are the most important QoS parameters. Application criticality is the second most important QoS parameter followed by security and cost. Recent research in m-Health community is experiencing a shift to user-based QoS characteristics, i.e., on the QoE, which, in turn, depends on technology-based QoS characteristics.

Based on available literature [16, 24–27], QoS requirements for the transmission of variety of healthcare data

Table 1 Summary of QoS categories and characteristics [15]

Technology-based QoS characteristics		User-based QoS characteristics	
Category	Characteristics	Category	Characteristics
Timeliness	Delay, response time, Jitter	Criticality	Importance (priority)
Bandwidth	System level data rate, application level data rate, transaction rate	Perceived QoS	Picture detail, picture color accuracy, video rate, video smoothness, audio quality, video/audio synchronization
Reliability	Mean time to failure, mean time to repair, mean time between failures, percentage of time available, Loss or corruption rate	Security	Confidentiality, integrity, non-repudiation of sending or delivery, authentication
		Cost	per-use cost, per-unit cost, power consumption

Table 2 Combined view of M-Health QoS parameters

	Timeliness	Bandwidth	Reliability	Criticality	Perceived QoS	Security	Cost
Ullah et al. [17]	Y	Y	Y	Y	Y	N	N
Kartsakli et al. [16]	Y	Y	Y	Y	N	Y	Y
Chakraborty et al. [23]	Y	Y	Y	Y	N	Y	Y
Salam et al. [18]	Y	N	Y	Y	N	N	N
Kang et al. [19]	Y	Y	Y	N	N	Y	Y
Alinejad et al. [20]	Y	Y	Y	N	N	N	N
Skorin-Kapov et al. [22]	Y	Y	Y	Y	Y	Y	N
Pawar [21]	Y	Y	Y	N	N	N	Y

Y considered, *N* not considered

are shown in Table 3. The QoS parameters considered in this table are data rate/bandwidth, delay, bit error rate, and criticality. The data presented in Table 3 are indicative and exact numbers and criticality level might vary depending on the sensors used and application requirement. The data rate/bandwidth requirements vary widely—from few Kbps to 40 Mbps depending on the sensor used. Depending on the application requirement, data collected from multiple types of sensors may need to be delivered to the back-end server simultaneously resulting in even higher required data rates. Real-time life-critical applications of MPMS are sensitive to delay and data loss [28]. Certain low data rate sensors such as blood pressure and SpO2 sensors may generate very time-critical data packets, which must be delivered at the destination sink within a guaranteed end-to-end delay deadline [29]. A loss of alarm packet/alert packet indicating critical situation of a patient has serious consequences. In contrast, some high data rate sensors (e.g., streaming of ECG signals) may allow a certain percentage of packet losses. Usually, BAN devices such as sensors and MBU have limited storage resources, and hence, it is required to transmit data to the back-end system as soon as it is collected by the BAN [28].

Table 3 QoS requirements for selected MPMS sensor data

Sensor	Data rate/bandwidth	Max. delay	Max. bit error rate	Criticality	Description
Deep brain stimulation	1 Mbps	250 ms	10^{-3}	High	Useful to treat Parkinson disease, tremors, dystonia
Hearing aid	200 Kbps	250 ms	10^{-10}	High	Sound amplification
Capsule endoscope	1 Mbps	250 ms	10^{-10}	High	Imaging of the digestive track
Drug dosage	1 Kbps	250 ms	10^{-10}	High	Deliver drugs in-body
ECG	72 Kbps (500 Hz, 12 channels)	250 ms	10^{-10}	Medium	Electrical activity of heart beats
EEG	86.4 Kbps (300 Hz, 24 channels)	250 ms	10^{-10}	High	Brain wave activities
EMG	1.536 Mbps, 12 channels)	250 ms	10^{-10}	Medium	Electrical activity of skeletal muscles
Blood pressure (BP)	10 Kbps	250 ms	10^{-10}	Low	Max and min blood pressure
Temperature	10 Kbps	250 ms	10^{-10}	Low	Body temperature
Respiration	10 Kbps	250 ms	10^{-10}	Low	Chest expansion/contraction
SpO2	10 Kbps	250 ms	10^{-10}	Low	Blood oxygen saturation level
Glucose monitoring	10 Kbps	250 ms	10^{-10}	Medium	Sugar level in the blood
Accelerometer/gyroscope	10 Kbps	250 ms	10^{-10}	Low	Body movements
Voice	1 Mbps	150 ms	10^{-5}	Medium	Voice interaction with patient
Sound Diagnostic	256 Kbps	100 ms	10^{-3}	Medium	In-body sounds
Medical imaging (un-compressed)	40 Mbps	100 ms	10^{-3}	Medium	In-body images
Medical imaging (ROI Jpeg)	19 Mbps	100 ms	10^{-3}	Medium	In-body images
Video	10 Mbps	150 ms	10^{-3}	Medium	In-body of patient video

3 QoS Performance Evaluation of Wireless Networks

As compared to wired networks, wireless networks consist of components that communicate using light or radio waves propagating through an air medium. Wireless networks facilitate user mobility throughout a campus, city or region. A Network Interface Card (NIC) provides capability to a computing device carried by a user to communicate over the air using an antenna that converts electrical signals to radio or light waves for propagation through the air medium. The obstructions in the air affect the quality of transmission by lessening or scattering the strength of the signals [30]. This section introduces a general architecture of wireless networks and summarizes studies reporting QoS performance evaluation of wireless networks for the transmission of healthcare data.

3.1 General Architecture of Wireless Networks

The functionality of wireless network is defined in terms of most popular architecture standard known as seven-layer Open System Interconnect (OSI) Reference Model developed by the International Standards Association (ISO). A physical layer (e.g., radio waves and light medium) provides the actual transmission of information signals. A data link layer consists of two sublayers: the Logical-Link Control (LLC) sublayer and the Medium Access Control (MAC) sublayer. It ensures medium access, synchronization, and error control between two entities. A network layer facilitates routing of information packets from source to destination. A transport layer provides mechanisms for the establishment, maintenance, and termination of virtual circuits between two entities. A session layer establishes, manages, and terminates sessions between applications. A presentation layer takes care of different data formats, while application layer provides basic communication services such as file transfer and e-mail [30]. However, wireless NICs directly implement the data link layer and physical layer functions. A wireless middleware may offer higher layer functions. The types of wireless networks and their examples are given in Table 4.

3.2 QoS Performance Evaluation Studies

The studies reporting performance evaluation for wireless networks are grouped as per the wireless network type. We have also added a case study on comparing battery life performance of a mobile device for transmitting healthcare data over multiple wireless networks [31].

3.2.1 Performance Evaluation of WPAN Networks

A simulation-based QoS performance evaluation study of three WPAN standards, namely IEEE 802.15.4, IEEE 802.15.6, and Bluetooth Low Energy, has been conducted in [24]. The scenario consists of transmitting data from sensor nodes distributed in a body to a receiver node that functions as a network coordinator. The performance is evaluated in terms of packet loss ratio, delay, and network throughput. It is observed that from the physical layer viewpoint, Bluetooth Low Energy provides the best performance working at larger bit rate. From the MAC layer viewpoint, IEEE 802.15.6 (WBAN) provides the best performance.

3.2.2 Performance Evaluation of MANETs

A performance evaluation of four routing protocols used in MANETs for the emergency telemedicine scenario is conducted in [25]. The scenario consists of a moving ambulance and a mobile pedestrian transmitting biosignals data to hospital in a WiMAX environment. The MANET topology consists of varying number of nodes (4–40 nodes) representing varying network sizes and random waypoint mobility model for the movement of nodes with varying speed. The routing protocols considered are Ad hoc On-Demand Distance Vector Routing (AODV), Location Aided Routing scheme1 (LAR1), Optimized Link State Routing Protocol (OLSR), and Zone Routing Protocol (ZRP). The QoS performance

Table 4 Types and examples of wireless networks

Wireless network type	Range	Examples
Wireless Personal Area Networks (WPAN)	Few meters	Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4), ultra-wideband—UWB (802.15.3), Wireless BAN (802.15.6)
Wireless Local Area Networks (WLAN)	~ 30 m	Wi-Fi (IEEE 802.11)
Mobile Ad hoc Networks (MANET)	Variable	May use WPAN and WLAN technologies
Wireless Metropolitan Area Networks (WMAN)	~ 50 km	WIMAX (IEEE 802.16)
Wireless Wide Area Networks (WWAN)	~ 100 s of km	1G (AMPS), 2G (GSM, IS-54), 3G (UMTS, CDMA2000, HSDPA), 4G (WIMAX, LTE), 5G (upcoming)

comparison metrics are average jitter, packet delivery ratio, average end-to-end delay, and throughput. The results show that the LAR1 routing protocol provides highest network performance, since it uses location information obtained from Global Positioning System for route discovery.

3.2.3 Performance Evaluation of WWANs

A scenario of possible continuous wireless ECG transmission using CDMA2000 is evaluated in [19]. The protocol layers considered for transmission are security and logical-link layers, MAC layer, and physical layer. Potential delay sources in filling a frame, encryption, and propagation delays are considered. An extensive simulation has been conducted for CDMA2000 1xEV-DO Revision-A network that supports reverse-link data rates from 4.8 to 1843.2 Kbps. The results of simulating cellular-based wireless ECG monitoring system suggest that the CDMA2000 cellular technology has considerable potential in real-time medical telemetry and M-health applications in general.

QoS performance evaluation of the 4G LTE network for biosignals transmission using NS-3 software is conducted in [26]. The simulation area is a model of peripheral highway in Cuenca city (in Ecuador) covering an area of more than 3 km^2. Among the two scenarios considered, the first scenario evaluates network performance, while mobile ambulances connect medical equipment to the 4G network, data transmission rate of 512 Kbps and three signal propagation path loss models—COST231, Log-Distance, and Friis. The results of first scenario suggest that the LTE network provides an average throughput of 513.59 Kbps when there is an unobstructed clear path between the transmitter and receiver (Friis model). However, the throughput decreases to less than 380 Kbps for two other models. The second scenario evaluates the performance of ambulance uplink data flow, while two other users inject traffic in the LTE network at the rate of 512 and 256 Kbps, respectively. The results of second scenario show that the LTE network performance decreases with the increase in number of simultaneous users.

The upcoming 5G networks are being studied extensively for evolving MPMS applications [32–35]. The key capabilities envisaged for 5G technology are the following [32, 34]: (1) peak uplink data rate of 10 Gbps and downlink data rate of 5 Gbps, (2) less than or equal to 1 ms latency, (3) support for high mobility (up to 500 kmph). It is envisaged that mobile femtocell (Mfemto)—a type of small cell network technology will play a significant role in 5G networks. A femtocell is a small, low-power cellular base station, typically designed for use in a home or small business and is expected to increase network coverage and capacity. The QoS analysis of medical video streaming using femtocells is reported in [32]. The simulation of femtocells is carried out using 4G LTE-Sim system level simulator for the transmission of ultrasound video sequence (25 fps, resolution 640 × 480, data rate of 128 Kbps) compressed using H.264 standard. The simulation has been conducted for the urban environment without femtocells and with femtocells with reference to the throughput, packet loss rate, and delay. The simulation results suggest that the use of femtocells for transmission of medical video resulted in significant performance advantages as compared to the traditional cellular networks.

3.2.4 Performance Evaluation of Battery Life

The battery life performance of a mobile device (Moto G 4G, 2nd gen. Android phone) for the transmission of healthcare data using Wi-Fi, 2.75G (EDGE), 3.5G (HSPA+), and 4G (LTE) wireless networks is reported in [36]. In the tested scenario, a wearable ECG sensor produced data at the rate of 25 Kbps and three transmission modes (“idle”, “continuous”, and “bundle”) have been tested for each of the above networks. In the idle mode, the wireless NI was up but unused. In the continuous mode, the ECG data were sent in real time to the back-end server using TCP session and in the bundle mode, the data collected over a minute were assembled in a bundle size of 187.5 KB. The test runs for the duration in which battery level dropped from 100% to less than 20%. The results of this experiment suggested that when the NI is idle, the smartphone battery lasted till 4–9 days depending on the network used. With continuous transmission, the battery life drops to about 2 days using Wi-Fi network and half day or even less for cell phone technologies. The bundle mode proved more effective than continuous mode (8 days of battery life for Wi-Fi network and about 2–3 days for cellular networks), as the wireless NI uses power-saving mode when the radio channel is not in use [36].

4 Approaches for Healthcare QoS Provisioning

There are several factors affecting QoS of wireless networks such as user mobility, number of users accessing the network, and interference. For example, in MANETs, the changes in node location result changes in network topology, and hence, a new path needs to be established for routing data packets. The routing nodes in MANETs maintain link and flow state information to take a decision on routing. The state information is imprecise and ever-changing due to dynamic changes in network topology, and hence, the routing decisions may not be accurate resulting in additional delay for sending packets [37]. In WWAN networks, as a result of patient mobility, the wireless network access point in use changes requiring handover from one access point to another and thus resulting in establishing a new connection path with different QoS characteristics. Most of the wireless technologies such as Wi-Fi, Bluetooth, and IEEE 802.15.4 operate in the radio band centered at 2.45 GHz. Co-channel interferences caused by use of these technologies result in higher latency in BAN communication [24].

QoS provisioning refers to providing support for improving QoS experience of networked applications. QoS provisioning approaches are broadly classified into two categories: hard QoS provisioning and soft QoS provisioning. If a network connection guarantees a certain level of QoS for the entire communication session, it is referred as hard QoS provisioning, which is mainly provided by fixed network connections and WWAN networks. If a certain QoS level cannot be guaranteed for entire session, it is known as soft QoS provisioning. Due to network dynamics in MANETs, hard QoS provisioning is a difficult task [37].

In addition to QoS provisioning in the wireless networks, the middleware supporting healthcare applications can be adapted to make best use of the available network QoS. E.g., using a vertical handover approach, the middleware selects most optimal network connection among the available ones for the transfer of biosignals. A review of e-health technologies and QoS provisioning in wireless telemedicine systems is conducted in [38, 39]. The QoS provisioning approaches discussed are: handover schemes, adaptive resource distribution plan for QoS provision, resource allocation using DiffServ mechanisms, hybrid optical-wireless broadband network, and using cognitive-radio based methods to address obstacles in wireless transmission of E-health data. In [40], QoS mechanism is defined as any method that improves the system performance in terms of QoS. The QoS mechanisms discussed in [40] are: service differentiation, collision management, clustering, data compression, error recovery, and power control. This section provides an overview of various approaches used by researchers in healthcare domain for QoS provisioning. Table 4 briefly compares QoS provisioning approaches presented in this section.

4.1 Service Differentiation and Access Priorities

Service differentiation and access priorities are mainly employed at the MAC layer and they refer to assigning different access priorities to traffic flows to meet specific QoS performance goal. The criteria used for priority assignment include data criticality level (e.g., emergency alarm vs. normal data) or QoS requirements such as delay constraints [16].

A data-centric multi-objective QoS-aware routing protocol named DMQoS for MANETs is proposed in [40]. DMQoS facilitates the system to achieve customized QoS services for each traffic category differentiated according to the generated data types. DMQoS employs a localized hop-by-hop routing technique by studying QoS performance of neighboring nodes and their geographic locations. DMQoS defines four types of priorities for data packets. The highest priority is given to the critical packets (ECG and EEG data); the second priority is given to delay-constrained packets (video imaging and motion sensing); the lower priority is given to reliability-constrained packets (e.g., BP and respiration monitoring); and the least priority is given for ordinary packets (e.g., glucose, SPO2, and body temperature). DMQoS also proposes solution to a starvation problem that refers to indefinitely blocking of lower priority traffic by higher priority traffic. A proposed solution consists of gradually increasing the priorities of packets waiting for transmission for a long period of time (Table 5).

An approach named BodyQoS [41] assigns priority for data streams according to the data type and level of criticality. Two types of nodes are considered: sensor node and aggregator node which collects data from sensor nodes. The QoS scheduler in BodyQoS is implemented as a virtual MAC that makes it easier to port QoS system from one radio platform to another. BodyQoS defines three classes of descending priority: reserved downlink data from the aggregator node to sensor nodes, reserved uplink data from sensor nodes to aggregator node and best-effort data. Reserved downlink data are scheduled first, followed by the reserved uplink data, if there is still available bandwidth. Any remaining bandwidth is devoted to best-effort traffic.

A packet scheduling scheme for real-time traffic is proposed in [24] which classifies the traffic according to its nature (real-time, emergency, or non-real time) and stores it into the high-and low-priority queues. The packets from the queues are served for transmission according to their priority and QoS requirements. QoS-aware data transmission solution presented in [42] collect and prioritize multiple biosignals data from different BANs in retirement home and hospital settings before transferring the acquired data to the service provides for processing. The QoS layer in a wireless ECG monitor proposed in [5] distinguishes two types of traffic as follows: burst traffic that generates data required for display (such as ECG display) and event traffic that may trigger a life-critical alarm. The QoS protocol in [5] provides priority to fresh events by transferring first newer events.

A proportional fair allocation control strategy to regulate the rate to data flow based on information priority at each router device is proposed in [43]. The strategy for determining priority considers bandwidth requirement for the reliable communication of a biosignal and level of emergency. A QoS-aware health monitoring system proposed in [44] considers two levels of priority—urgent and non-urgent. A data scheduling scheme proposed in [45] considers three types of traffic—on-demand, emergency, and normal traffic. After fixed interval, a packet scheduler calculates the critical delay of each packet and packets with lowest critical delay are served first. This scheme results in reducing waiting delays and improving throughput. A dynamic priority-based

Table 5 Comparison of mechanisms for optimal delivery of biosignals

Approach	Pros	Cons	Suitable situation
Service differentiation and access priorities	Preference given to traffic with high emergency level (e.g. critical alarm event)	Differentiated service network may drop some packets to give priority to other important traffic	Suitable for E-Health applications with clearly defined QoS traffic requirements and priority levels
Cross-layer scheduling	Take into account cross-layer info. of other layers such as physical, network and application layers to take a packet scheduling decision	It is challenging to acquire real-time cross-layer info. from entities in other layers. E.g. routing data might get stale soon due to mobility	Suitable in the environment with high variance in noise and interference as well as varying application QoS requirements
QoS mapping	No special QoS provisioning mechanism is required as mapping is done onto QoS classes defined by network operator	Dependency on the QoS classes defined by network operator. May not be suitable for arbitrary QoS requirements	Suitable for the situations where QoS provided by network operator is sufficient for healthcare application
Vertical handover	Dynamic, adapts to the heterogeneous network environment	Requires context sources to continuously scan the network environment	A patient moving in indoor/outdoor environment
Biosignals compression	(Significant) reduction in image size/biosignals data size to be sent, selection of only required region image data	Processing power/time required on mobile device/back end to compress/decompress data	ECG monitoring, transmission of 3D images of MRI & CT scan

QoS management protocol that controls congestion in the network and also provides a timely delivery of a packet is proposed in [46].

4.2 Cross-Layer Scheduling

The cross-layer scheduling algorithms take into account cross-layer information acquired from the interaction of the MAC layer with other protocol layers for taking a scheduling decision [16]. Cross-layer parameters include routing information from the network layer or channel-state information provided by the physical layer, among others. Cross-layer approaches improve the overall QoS performance as QoS requirements at the application layer could also be provided to the MAC layer for a better allocation of communication resources [47].

The Distributed Queuing Body Area Network (DQBAN) protocol [48] uses a cross-layer fuzzy rule-based scheduling algorithm as an alternative to MAC layer protocol of 802.15.4 technology to improve QoS and energy efficiency. The cross-layer information considered by body sensors is physical layer signal quality, packet system waiting time, and residual battery lifetime. This information is used by a fuzzy-logic-based cross-layer scheduler to take a decision on permitting or refusing transfer of sensor data in the next frame. The simulation results show that the DQBAN performs better when there are more nodes in a network, and it provides a better QoS support together with reduction in energy consumption. A cross-layer scheduling protocol that also combines concept of packet priorities is proposed in [47]. Three user priorities of data packets are defined as follows: emergency data (first priority), medical video data (second priority), and regular measurement data (third priority). The protocol proposed in [47] takes into account application QoS requirements and parameters of physical layer.

4.3 QoS Mapping

In the current era of voice/video/data convergence, WWAN network operators provide in-built QoS support by prioritizing the traffic for variety of flow types to attract a tiered range of subscribers. QoS mapping refers to mapping of biosignals data QoS requirements onto QoS classes defined by network operators for guaranteed delivery. For example, the WiMAX standard prioritizes the traffic into following four classes: (1) Unsolicited Grant Service (UGS) for Constant-Bit-Rate services such as VoIP; (2) Real-Time Polling Service (rtPS) to support real-time periodic service flows such as MPEG video; (3) Non-Real-Time Polling Service (nrtPS) to support variable size data packets such as FTP; and (4) Best Effort (BE) which support data streams that do not require minimum guaranteed rate. In [20], mapping of medical QoS to IEEE 802.16/WiMAX QoS parameters is given to optimize the performance of e-Health services. ECG, BP, and heart rate traffic are mapped onto UGS class. Medical images such as MRI and radiology images are mapped onto nrtPS class. Streaming data traffic such as ultrasound video streaming, video, and voice conferencing are mapped onto rtPS class. Similarly, mapping of QoS requirements of e-Health services onto QoS classes of Evolved Packet System (EPS) is proposed in [49].

4.4 Vertical Handover

The term vertical handover refers to a switchover from one network connection to the other network connection for the exchange of data. These days handheld mobile devices are equipped with multiple wireless network interfaces (e.g., WWAN and WLAN). The patient mobility may result in sudden disconnection from the wireless network in use by the multi-homed mobile device. In this case, vertical handover technique can be applied to select the other available wireless network unobtrusively to support seamless roaming connection availability if an alternate network is available [50]. An alternate network could also be selected on detecting degradation of QoS performance of network in use.

A handover management process refers to the selection of appropriate time to initiate handover and making a decision about the most suitable wireless network to maintain wireless connectivity. The information which can be identified to take a handover decision can be classified into following four categories: (1) network-related information includes parameters such as wireless network coverage, offered QoS, Received Signal Strength (RSS), and security level; (2) terminal (handheld)-related parameters include velocity, battery power, and location information; (3) user-related parameters are user profile and preferences; and (4) service (application)-related parameters include QoS requirements.

A context-aware vertical handover mechanism for the biosignals transmission in mobile patient monitoring is reported in [21]. The communication context source provides real-time information about types of wireless network to which the MBU is connected, IP address of MBU network interfaces and whether the network provides Internet connectivity. To take into account changes in the network availability, a handover decision-making phase is initiated whenever a new wireless network is detected, or when the MBU disconnects from the current wireless network in use. The results of experimental evaluation demonstrated the feasibility of vertical handover for the biosignals transmission.

4.5 Biosignal Compression

Researchers have been studying use of compression techniques for energy-efficient transmission of healthcare data. A wireless NIC of a mobile device consumes significant amount of energy for the transmission of data [36]. This energy consumption is directly proportional to the duration of transmission and amount of bytes transferred. Hence, using compression techniques to reduce the amount of data to be sent has an advantage of reducing power consumption of a mobile device as well as optimal utilization of available network resources by reducing link-level congestion [51, 52]. Basically, compression techniques are of two types: Lossy and Lossless. Lossless compression techniques do not allow the loss of information in the reconstructed signal, while lossy compression techniques produce some loss of information in the reconstructed signal.

A survey of medical image compression methods is given in [53]. The compression of healthcare data is challenging as the compression algorithms should permit minimum loss of information so as not to contribute to diagnostic errors and still have high compression ratio for reduced transmission time [53]. Some of the common techniques used in the compression of medical images are JPEG2000, Discrete Cosine Transform, and Discrete Wavelet Transform (DWT). ECG waveform compression is also a popular subject of research. Compressed sensing is a newer generation signal-processing technique that is increasingly used for ECG compression as an alternative to the state-of-the-art DWT-based ECG compression [53, 54].

5 Conclusions and Directions for Further Research

The vision of pervasive healthcare aims at providing healthcare to anyone, anytime, and anywhere by removing geographical, temporal, and other limitations while increasing both the coverage and quality of the pervasive healthcare systems [55]. Mobile patient monitoring is a promising technology towards achieving this vision. In this survey paper, we presented recent developments in QoS provisioning for biosignals delivery in a Mobile Patient Monitoring System (MPMS). An MPMS is a set comprising of a Body Area Network (BAN) which acquires biosignals from a patient and Back-End System (BESys) that provides personalized healthcare applications to a patient based on assessment of biosignals. The wireless communication technologies used in the MPMS fall into multiple categories (WPAN, WLAN, and WWAN) each with a number of technology implementations. An important research challenge in the MPMS is how to satisfy QoS requirements of biosignals delivery in the environment characterized by patient mobility, deployment of multiple wireless network technologies, and variable QoS characteristics of the wireless networks.

In this paper, we presented a combined view of QoS characteristics considered by M-Health researchers. Most of the approaches consider timeliness, bandwidth, and reliability as the most important QoS parameters for biosignals transmission. Application criticality is the second most important QoS parameter followed by security and cost. Recent research in m-Health community is focused on user-based QoS characteristics, i.e., on the QoE, which in turn depends on technology-based QoS characteristics. QoS requirements for biosignals transmission are dependent on the type and number of sensors used in the BAN and intended healthcare application. The QoS requirements are the most stringent for emergency situations which require immediate attention from the healthcare professionals.

The survey on performance evaluation of wireless networks for the transmission of biosignals suggests that as the wireless networks evolve in the capacity, they are becoming increasingly more suitable for mission-critical healthcare applications like MPMS. The newer generation WPAN standards such as 802.15.6 WBAN provide superior QoS performance for biosignals transmission as compared to their predecessors Bluetooth and ZigBee. As the mobile terminals are increasingly equipped with GPS hardware, the MANET routing protocols such as Location Aided Routing Scheme (LAR1) have proved to provide superior QoS performance as compared to their counterparts AODV and OLSR. As compared to their predecessor 2G and 3G networks, the 4G networks provide higher throughput for the transmission of biosignals. With the advent of 5G networks, it will become feasible to transmit high-resolution ultrasound video images in real time to the hospitals. However, there exist challenging situations such as high number of simultaneously active users and signal attenuation due to obstacles in providing a consistent wireless network QoS performance for patient monitoring. Since next-generation wireless networks require higher energy for data transmission, yet another challenge is to design an energy-efficient biosignal transmission strategy.

We cited multiple approaches along with relevant examples for QoS provisioning in MPMS. These approaches are as follows:

1. The service differentiation and access priority approach assign different access priorities to biosignal traffic flows to meet specific QoS performance goal—such as immediate transmission of event packets indicating emergency.
2. The cross-layer scheduling algorithms take into account information acquired from the interaction of the MAC layer with other protocol layers for taking a scheduling decision.
3. The QoS mapping refers to mapping of biosignals data QoS requirements onto QoS classes defined by network operators for guaranteed delivery.
4. A vertical handover approach can be applied to improve reliability and availability of data connectivity by switching over to another wireless network in the event of network disconnection or QoS degradation.
5. The biosignals compression technique can be used to reduce the amount of data to be sent and thereby reducing power consumption of a mobile device.

It is to be noted that no single approach is the best solution, while some of these approaches are complimentary to each other.

As a direction for further research, we propose integrating QoS requirement consideration, QoS monitoring, and QoS optimization strategies in an MPMS infrastructure, as shown in Fig. 2, to support optimal delivery of biosignals

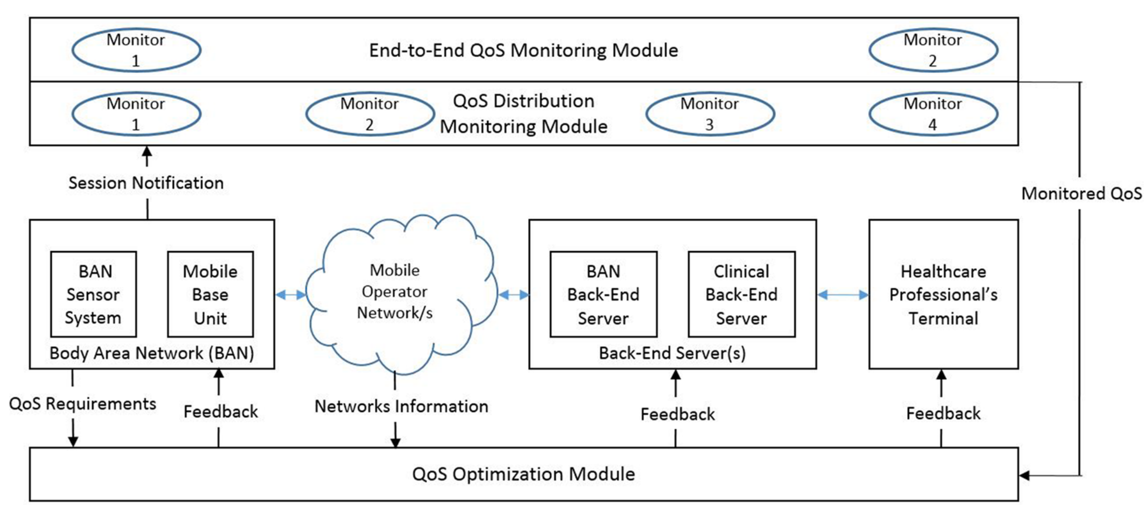

Fig. 2 Integrating QoS requirements elicitation, QoS monitoring, and QoS optimization

to the healthcare professionals. In the beginning of a mobile patient monitoring session, a notification is sent to the QoS monitoring module which is responsible for measuring end-to-end QoS or QoS distribution along biosignals delivery path. The QoS requirements and network availability information are sent to the QoS optimization module. As the session progresses, the QoS monitoring module periodically informs monitored QoS-to-QoS optimization module. Based on the QoS requirements, available networks, and monitored QoS, the optimization module takes a decision to implement a certain QoS mechanism (such as context-aware vertical handover or service differentiation) for biosignals delivery. This decision is sent as a feedback to the MPMS for its implementation. It is also an interesting future work to come up with a telemedicine QoS data set that could be used as a reference for the performance evaluation of QoS provisioning approaches in MPMS.

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