Hybrid Network Based Automated Cardiac Telemedicine System

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Abstract

This paper presents design overview of a novel cardiac telemedicine system comprising of geographically distributed network enabled ECG analysis, diagnostic and telemetric stations connected with regional cardiac care centers via LAN/WLAN, PSTN, Multi-GSM/GPRS, VHF/UHF radio and Satellite. ECG analysis and diagnostic software, patient management system and a multimedia database, installed at the physician end, allows cardiologists to retrieve ECG data and patients' profile from remote locations and provide them with their recommendations. Availability of multiple physical interfaces for transmission not only allows extended coverage but also timely diagnosis for immediate causes of concerns anytime, anywhere around the world.

1. Introduction

Increasing number of heart patients and swelling statistics of mortality rate due to cardiac problems demand an efficient system pertinent to cardiac care at every level of health centre. Studies have revealed that in developing countries like UK, among patient above 55 years old, who die from cardiac arrest, 91% do so outside hospital [1]. Statistics in developing countries are far worse, where dilemma is not just the dearth of clinics and physicians but an imbalance in doctors' distribution geographically with many remote clinics without even a qualified physician. Cardiac patients at these understaffed sites do not get timely medical diagnosis and proper treatment. However, in this era of sophisticated communication and information technology, potential patients can get advanced emergency care by transmitting their physiological data to experts at metropolitan cardiac care centres in real-time.

Information Technology (IT) has transformed the ways modern healthcare systems acquire, store, access and communicate medical information [2]. Remarkable ease in accessibility and rapid transmission of healthcare information over the internet is no less than a revolution in medical practice. A number of telemedicine applications/systems have been developed and reported in literature which incorporate PSTN [3], 2G/2.5G/3G mobile [4], eHit Health Gateway [5], IEEE 802.16 - based Broadband Wireless Access (WiMAX) [6], IP based Very Small Aperture Terminal (VSAT) satellite communication and Wireless Local Area Network (WLAN) [7] technologies to provide telemedicine services. Today, telemedicine applications demand automated and continuous services and proactive real-time collaborations among devices, software agents, networks and geographically distributed factors (such as doctors, clinicians and patients) in dynamic, heterogeneous environments [8].

Despite rapid growth in wireless communications including cellular and ad hoc networks, wireless LANs, VHF, UHF and Satellite links, no single wireless access technology can provide optimum connectivity. Optimum connectivity requires performance in terms of network coverage, transmission power, delays, mobility support etc. to mention a few [9]. For this purpose, a hybrid network-based cardiac telemedicine system is developed which allows patients at any geographical location to transmit their physiological data through a universal communication module with multiple physical interfaces to get 24/7 expert consultations in real-time anywhere around the globe. For ubiquitous connectivity across any geographical area, VHF, UHF and LAN/WLAN serve as short range communication technologies whereas Satellite, PSTN and GPRS technologies may span the entire globe. The developed system is equipped with ECG analysis software, capable of beat and rhythm classification and performs heart rate variability analysis. Server located at the regional hospital acquires ECG data from remote clients, records and transmits physicians' recommendations in real-time and stores ECG data in a database for offline data mining and future reference. The developed telemedicine system can be incorporated at any geographical location such as remote places, rural areas, home monitoring and vehicular environments like ambulances, ships, airplanes to mention a few.

2. Methods

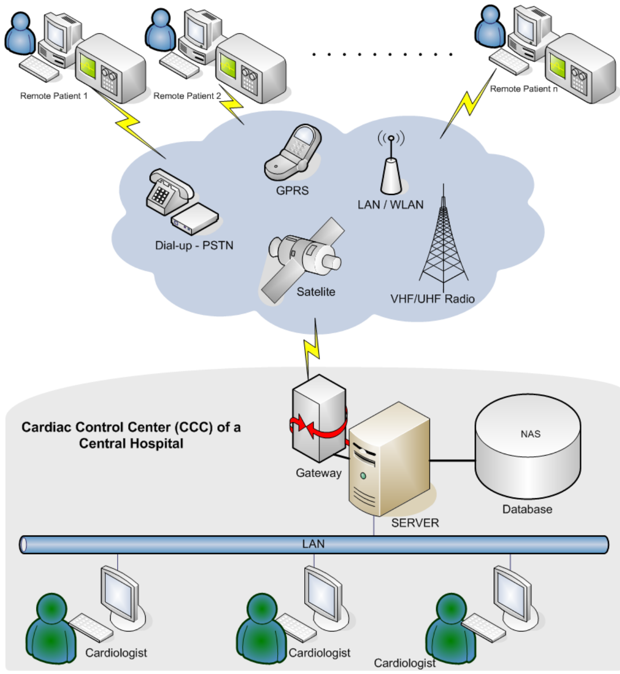

Figure 1: Architecture of the developed system

2.1 System Architecture

Figure 1 shows network architecture of the developed system. Each client node comprises of a commercial digital ECG machine connected with a computer terminal equipped with indigenously developed diagnostic software and a universal communication module. These nodes are geographically distributed and connected with the central hospital's Cardiac Control Centers (CCC) via hybrid network of LAN/WLAN, PSTN (dial-up), GSM/GPRS, VHF/UHF Radio and Satellite. Whenever any abnormality is detected in a patient's ECG, it generates an alarm at the server. Server receives physiological data from remote patients, generates an ECG work-list and initiates ECG workflow. Terminals at the cardiologist end are thin clients who are able to acquire physiological details and ECG profiles of the patients assigned to them by intelligent physician assignment software module. Cardiologists provide their recommendations and server transmits them back to the remote locations in real-time. If cardiologist is not present, the data is saved in a message box which may be retrieved at a later time by the cardiologist. All the records including patient profile and medical history are managed in a database of local ECG repository.

2.2 ECG Analysis Software

Complete ECG analysis software is developed in .NET C#. ECG analysis routine is depicted in figure 2. First step in ECG processing is noise removal. Noise is of several kinds and origins such as baseline wanders, power line interference, muscle artifacts, wide-band gaussian noise and noise from other electronic instrumentation [10]. Baseline wandering was removed using polynomial fitting algorithm by detrending the ECG signal using a forth order polynomial and then subtracting the deviation of the detrended signal from the mean line. Powerline interference was removed using an adaptive notch filter [11]. Wideband noise was removed by using an undecimated wavelet decomposition algorithm [12]. Finally the denoised signal is reconstructed from these modified coefficients. Principle Component Analysis (PCA) was used in conjunction with above techniques to remove muscle artefacts noise and other noise sources [13].

ECG fiducial point locator and morphology comprehension algorithm based on Wavelet Transform (WT) techniques as proposed in [14], was developed. Using a quadratic spline wavelet, signal singularities were detected and delineation of P, QRS and T wave peaks, onset and offset points was done using local maxima of the wavelet coefficient signals.

An auto-associative neural network [15] and an autoregressive modeling algorithm [16] was used for beat classification which is able to classify up to six different beat types including NSR, PVC, APC, VT, SVT and VF with an accuracy of 93.2% to 100%. Network was trained using MIT-BIH NSR and Arrhythmia databases [17].
After beat classification, ectopies were removed from the original signal. Statistics of beats other than sinus beat are an independent parameter for arrhythmia and abnormality detection. Series of NN intervals (RR intervals, PP intervals, QT intervals, PR Intervals and ST segments) resulting from sinus beats were used for subsequent heart rate variability analysis.

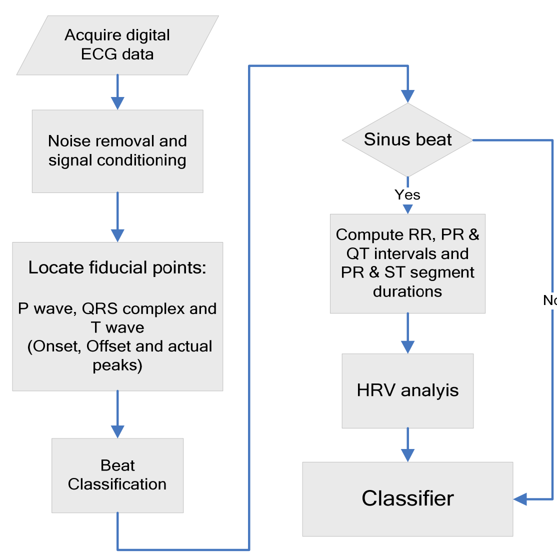

Figure 2: ECG processing and analysis routine

Heart rate variability analysis incorporated in our software was based on standards documented by the Task Force in [18] and other novel techniques [17]. Analysis was performed in time domain and frequency domain. In addition to this, nonlinear analysis of extracted parameters was also done. Nonlinear techniques include approximate entropy, sample entropy, detrended fluctuation analysis, information based similarity index, Multiscale entropy analysis, modified Karhunen-Loeve' transform, T wave-alternans and heart rate turbulence.

Results from beat classification stage and those resulting from heart rate variability analysis are fed to an indigenously developed neuro-fuzzy classifier and abnormality factor is computed. Abnormality factor near zero corresponds to that of the normal ECG whereas an abnormality factor close to 1 corresponds to serious abnormalities. Details of the developed classifier design are found in [19]. ECG signals with abnormality factor higher than 0.2 are transmitted to the server located at the central/regional hospital.

2.2 Universal Communication Module

The developed universal communication module incorporates multiple physical interfaces and networks for ubiquitous connectivity by utilizing multiple medias in patches of geographical region. Module is based on a universal communication gateway incorporating an intelligent communication controller and multiple physical interfaces for universal coverage. It integrates a LAN/WLAN and VHF/UHF radio based mobile ad hoc networks (short range communication technologies) with GSM/GPRS, PSTN and Satellite Networks (technologies that can span the entire globe). The controller automatically selects and switches to most optimal network technology based on availability of service, cost-effectiveness and pre-defined *Quality of Service (QoS)* criteria**.** TCP/IP was chosen as network protocol for communication, which ensures safe data transmission and interoperability over different physical interfaces. The system has event driven architecture and is developed on IEEE POSIX 1003.1c standard. Details of the communication module can be found in [9]. As the system possesses the capability of “any place and any time connectivity”, it is ideally suited for areas which are not easily accessible and are not covered by commercial mobile communication and networking technologies.

2.4 Server – Cardiac Control Center

Gateway at the Server receives ECG data from different networking technologies using TCP/IP protocol. Received data is first organized and stored in a patient management system which stores and manages patients’

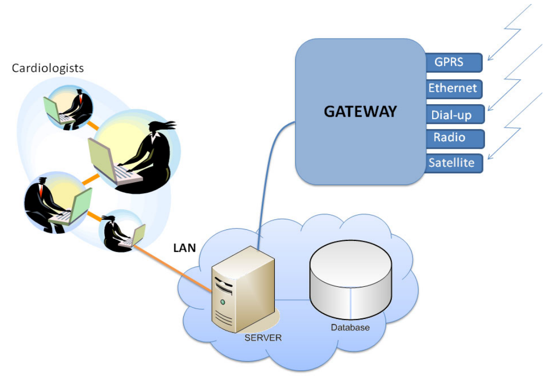

Figure 3: Gateway at server end

demographic profile, medical history, personal details and ECG data to mention a few. Next, software does intelligent physician assignment based on availability of the physician, specialization level of physician and priority level of the patient. Message-list at physician’s end shows active patients waiting in queue for remote consultations. Here physicians are able to retrieve patient’s data, his/her medical information, medical history as well as the received ECG waveform. ECG analysis software is also installed on physicians’ machines which aid them for in-depth analysis and better diagnosis. Once physician updates his recommendation, it is transmitted back to the remote client. Server stores complete patient information and diagnosis in the local repository for offline data mining and future reference.

3. Results

Figure 4 shows GUI of the developed software. Three ECG waveforms shown in the figure are i) raw ECG signal, ii) denoised ECG signal and iii) annotated ECG signal with fiducial points marked and boundaries of P wave, QRS complex and T wave delineated. Figure 5 shows physician front-end at the cardiac control center.

Figure 4: GUI of the ECG analysis software

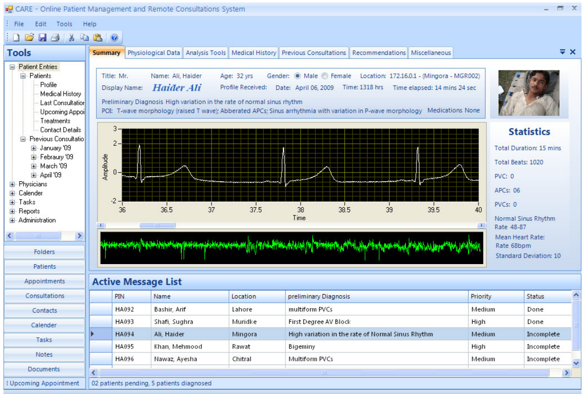

Figure 5: GUI of PMS at physician front end

4. Discussion and conclusions

This paper presents a novel telemedicine system which integrates multiple networking technologies for extended coverage to provide expert consultations to remote patients with immediate causes of concern. Key components of the system are intelligent diagnostic software, communication module and the patient management system.

Prototype of this system with four client nodes is recently installed at different remote villages in Pakistan, namely Mingora, Rawat, Chitral and Muridke. Central server is established at the Armed Forces Institute of Cardiology (AFIC), Rawalpindi. Prototype has successfully completed its first of three validation stages and emerged as a successful proof of concept prototype.

The developed system opens a new horizon of ubiquitous computing based telemedicine applications, where connectivity is of prime importance on wider physical space including patches of land not covered by commercial networking technologies. The 24/7 connectivity and self diagnosing capability of the system will be equally helpful for both under-developed and developing countries where ubiquitous connectivity and timely diagnosis is main cause of concern.

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