GDAŃSK UNIVERSITY OF TECHNOLOGY FACULTY OF ETI ANNALS
No 8 Information Technologies 2010

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BODY AREA SENSOR NETWORK WITH AUTOMATICALLY SELECTED TRANSMISSION GATEWAYS

Abstract

Body area networks (BANs) are recently an innovative proposal for integrating data from wearable sensors in multimodal health and behavior surveillance systems. To allow unlimited subject's mobility, they commonly use wireless long-distance transmission (e.g. GPRS) requiring considerable amount of power, particularly in buildings, where the radio carrier is weak. We postulate to embed in the BAN an additional short-distance gateway (e.g. WiFi or Bluetooth) communicating with the corresponding access point being part of subject's house or workplace infrastructure, and providing a wired connection with the health center. This paper presents the project and test results of a simple prototype of human surveillance system with automatic switching between the short- and long-distance data gateway depending on the subject localization. Assuming the subject is spending up to 80% of the monitoring time within closed areas, the prototype allows to save a considerable amount of money for the communication service, and to raise the autonomy of the sensor network by 41%.

1. INTRODUCTION

Wearable recorders of medical signals and complex multimodal body sensor networks (BSN) use local storage or direct transmission of raw data or diagnostic reports. The latter option gives a frequently appreciated advantage of immediate reporting, allowing for interactive remote diagnosis and therapy [1-5]. Long-distance wireless communication, although designed for providing unlimited subject's mobility, has several drawbacks like limited bandwidth, considerable costs and unstable connection quality, in particular within buildings [6].

Taking into account that an average, professionally active human spends 80% of his or her living time within buildings (45% in living premises, 35% in the office), we found reasonable to extend the design of a typical BSN by an additional short-distance communication gateway. Such approach enables the alternative digital data transmission with use of building-embedded infrastructure and wired access to the Internet. The role of data transfer service (DTS) may be fulfilled by a regular wireless local area network (WLAN) often already present in offices, or by a monitoring system being a component of an intelligent house personalized for the health-monitored subject [7]. This paper presents particular measures designed for the automatic selection of the optimal transmission gateway and for maintaining of data continuity during the carrier switching.

2. PRINCIPLES OF COMMUNICATION GATEWAYS SWITCHING

Implementing of the alternative data transfer gateway requires a precise definition of selection rules and strict control of the data flow. These issues include:

- conditions of carrier detection and selection of DTS,
- authentication of a wearable BSN-based monitoring system as a client of selected DTS,
- data continuity service, backup and confirmation.

2.1. Automatic selection of data transfer service

With regard of the postulated automatic selection of BSN data transfer gateways, the communication of a wearable system as a client of stationary DTS may be considered as:

- conditional integration of a DTS wireless interface into the BSN,
- application of a separate service using an additional short-distance wireless gateway enabled within the BSN alternately to the long-distance service.

The first option seems to be simpler and functional enough, as far as cooperation of only two systems is considered. Extending the cooperation of the BSN to multiple DTS in subject's home, office, vehicle, etc., requires them all to follow a set of common network-specific settings. Additionally, the Bluetooth technology commonly used as support of BSNs limits the number of simultaneously registered devices. Finally, for the support of monitoring of multiple subjects in multiple premises, a BSN-independent, standardized communication module is more appropriate (Fig. 1).

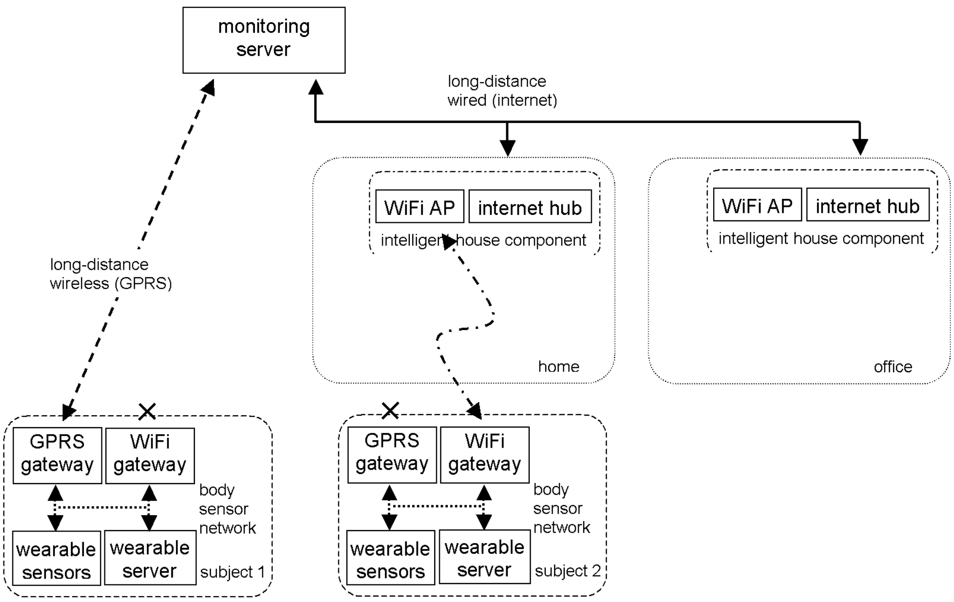

Fig. 1. Data transfer services for health monitoring sensor network with alternative gateways

2.2. Authentication of wearable system in data transfer service

For the reason of energy saving, the wearable short-distance communication module is always switched to the low-power receiver mode if the subject is outdoor and the BSN uses the long-distance gateway. The stationary DTS system is continuously propagating the premise-specific identification data. Once these data are received by the BSN, the wearable communication module is set up to the transmitter mode and sends the request for DTS and the subject identification. Since the wearable monitoring system is designed as strictly personal, detection of the BSN performed by the DTS system is equivalent to detection of subject's presence. The purpose of presence detection is threefold:

– informs about the subject's position,
– authorizes the subject as a client of the building-embedded monitoring system, and his wearable system as a client of DTS provided by the embedded system,
– identifies a subject-specific monitoring setup for downloading to the embedded system.

The authentication of cooperating devices is based on their unique identification numbers. Additionally, for each data exchange session the unique identifier is imposed by the server. These two labels, completed by the packet number and time marker are used for correct assignment of data contents, source, recipient and its temporal dependencies.

2.3 Data buffering and continuity service

In wireless applications using data carriers of variable throughput the data continuity is particularly endangered. Most of regular solutions rely on TCP/IP data control mechanisms, although due to delay on gateway switching, additional data buffering was designed in the proposed BSN for maintaining the continuity of diagnostic data transmission. This prevents an occasional data loss caused by radio carrier discontinuity or an unpredictable time and result of negotiations between DTSs.

Three data recipients are designed for the wearable BSN-based monitoring system:

– a long-distance wireless link being a default communication gateway,
– a short-distance wireless link working alternately within buildings and
– a circular memory buffer working continuously in parallel as the data backup.

The capacity of a circular buffer was designed for 10 MB what corresponds to over 25 minutes of storage for 8-channel ECG data (500 sps, 12 bits per sample) with diagnostic results (ca. 48kbps). The buffer capacity determines the maximum continuous recording time with no availability of wireless DTSs (e.g. remote areas, not WiFi-enabled buildings or air transport). The buffer contents is exclusively attributed by three separate pointers as written, read or deleted (Fig. 2).

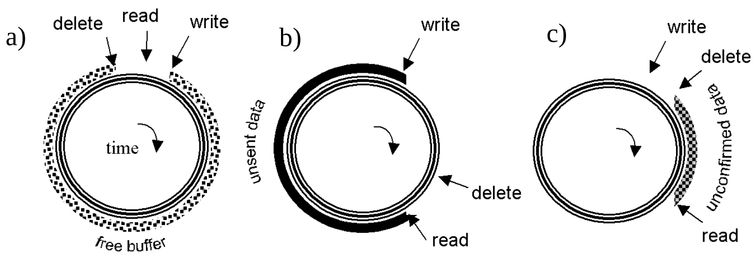

Fig. 2. Data buffering in health monitoring sensor network with alternative gateways. a) smooth data transmission allows for immediate deletion, b) large delays of transmission is allowed thanks to buffering of unsent data, c) buffered data are kept until the server confirms the reception.

The management of pointers is subject to the following rules:

– the write pointer is moving forward only, each time the patient data are ready to sent,
– the read pointer is advancing each time the data packet is sent to the communication module, but it may be set backward by the negative recipient confirmation,
– the delete pointer is moving forward only, each time the data reception is confirmed.

This supplementary mechanism for data flow control requires server-side confirmation of data reception for the advancement of the delete pointer. If the packet delay exceeds a given time, the server issues the negative recipient confirmation with the missing packet ID which returns the read pointer to a specified location of the circular buffer.

Subject to availability of wireless DTSs, the writing, reading and deletion of data are asynchronous. A state of the wearable BSN is therefore determined on the distance between the pointers as:

– the connection state - the read pointer is following the write pointer at the same average speed, the subject's health information at the recipient is synchronous,
– the follow-up state - the read pointer advances faster than the write pointer decreasing data delay, the subject's health information at the recipient is asynchronous,
– the data delay state - the read pointer advances slower than the write pointer increasing data delay, the subject's information at the recipient is asynchronous,
– the low memory state - the write pointer is approaching the delete pointer causing a free memory alert, the continuity of subject's health information is endangered.

Data packets contain time markers, therefore when collected by the recipient their synchronicity may be determined as the delay between the time marker and the local clock. The border value allowing for interactive diagnosis and therapy is usually set to 5 s.

3. DETAILS OF PROTOTYPE TWO-GATEWAYS BSN DESIGN

The prototype of the wearable system was designed as a cardiology-oriented personal monitor including MW705D GPS receiver (Mainnav), Aspekt500 12-leads ECG recorder (Aspel), TeleMyo 2400 G2 Telemetry System (Noraxon) and PXA-270 portable evaluation kit (Collibri) powered from the 4800 mAh 7.2V Li-Ion rechargeable battery pack [8-9]. Four components of BAN were interconnected with use of Bluetooth class II interfaces. In case of using the long-distance wireless connection, the GPRS throughput limits the datastream to 2 channels (upstream link of max. 16 kbps). The use of a short-distance DTS allows to send all 8 channels, and with a maximum assumed bandwidth of 500 kbps the BSN in the follow-up state synchronizes monitoring within less than 160 seconds.

The experimental DTS infrastructure was designed with two stationary WiFi access points placed in separate remote rooms called "home" and "office". Volunteers wore a BAN-based monitoring system providing raw ECG traces and the following diagnostic data: heart rate, beat type, ST-T segment parameters [10], time-domain Heart Rate Variability (HRV) parameters [11], and electrocardiogram-derived respiratory signal [12]. Additional datastreams were provided by wrist-mounted three axes accelerometers and Global Positioning coordinates updated every 5 seconds. Each room provided a wired broadband internet connection (Ethernet 100 Mbps); the monitoring server was a typical PC-based workstation with the static IP address.

4. RESULTS

Two volunteers wore the BSN-based cardiomonitors for the total of 14 days each, moving between the rooms at least 10 times daily, and performing physical exercise or resting accordingly to a predefined schedule. Besides the cardiac parameters (ST-T, HRV and EDR), subjects' data were investigated towards the identification of four basic states accordingly to [13-14]: working, walking, resting and sleeping. For each subject, transitions between states occurred 47 (+/-12) times and data carrier switching was performed 211 times.

The main result from the experiment was the delay measured between consecutive data packets travelling through different gateways and the average success rate for a single connection attempt. These data are summarized in table 1.

Table 1

Delay time between the packets using the standard and alternative data carriers

switching direction	success rate [%]	average delay time [s]	standard deviation delay time [s]
wireless to wired	93	6.35	1.05
wired to wireless	71	17.3	8.10

The results of the experiment confirmed also our expectations of a considerable extension of the wearable monitor autonomy time to 23 h (versus the initial 16.3 h, i.e. by 41.1%) and economical savings on long-distance wireless communication service. The initial daily costs of 32.7 USD was reduced to 6.55 USD, that is by 80%. The correctness of cardiology- and motion-based subject's state recognition varied from 93% (walking) to 67% (sleeping).

5. DISCUSSION

The proposed infrastructure guarantees quasi-continuous monitoring thanks to the automatic switching of transmission gateways. However, in case of a lost connection, the data available to the server are asynchronous. The proposed cardiology-oriented set-up aims at investigating the subject in his or her everyday living conditions in order to assess a danger from the coronary disease or sleep apnea. The set-up could be almost freely adapted to the subject’s need by using of different sensors and interpretation software.

The postulated application and automatic switching of alternative communication gateways is an advantageous advancement of mobile health monitoring in three aspects:

- improvement of data link reliability and extension of the bandwidth in buildings,
- reduction of communication costs and lengthening of the wearable recorder autonomy,
- feasibility with minimum expenses and with use of standard telecommunication devices; in an Internet-enabled building, the infrastructure costs is returned within three days of monitoring.

Comparing to wearable monitors with a single data transfer gateway, currently commonly used in clinic and research, the application of alternative communication service increases the probability of data synchronicity. This issue is of a particular interest in aspect of interactive remote diagnosis and therapy, since the remote modification of subject's behavior, medication and medical intervention may be applied upon necessity. Also from the patient's safety point of view, low-delay systems for health monitoring well simulate the continuous presence of the medical staff, without limiting the patient's mobility.

Automatic recognition of the subject’s states is the direction of future research as it opens the area of lifestyle control as a prospective application of monitoring systems. The other area for improvement is extending the building-embedded infrastructure by monitoring functionality. This approach can be particularly efficient in premises designed for elderly or disabled people to extend their professional activity and to improve their living conditions.

ACKNOWLEDGMENT

The scientific work supported by Polish State Committee of Scientific Research in the years 2009-2011 under the grant no N518 426736 (18.18.120.875).

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