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ECG Signal Transmissions Performance over Wearable Wireless Sensor Networks

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Abstract

Sudden death is the most common disease of heart diseases and usually caused by cardiac arrest. The electrocardiograph (ECG) system is the most direct way to observe and monitor health status of the heart. In this kind of disease, the patient may need continuous monitoring, and sometimes is kept in Intensive Care Unit (ICU), which needs more utilities and manpower that will eventually leads to increase the cost and demands for qualified medical staff. In this paper we introduce a comprehensive real time monitoring ECG system for continuous monitoring patients inside/outside home. Wearable Wireless Sensor Network with a cluster head is connected to patient body for monitoring. Measured data by WWSS are transmitted via cluster head to an internet connection to the monitoring system located on the hospital. In case of emergency, the measured data is sent to the physician's cell phone for any necessary actions. We discuss the inside/outside system structure. Additionally, we analyze the proposed system in terms of power consumptions and optimum distance between WSN sensors.

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Keywords: Portable ECG, Wireless Sensors Networks, Network Lifetime, Bitrate, Blood Pressure

1. Introduction

Cardiovascular disease is number one killer in Saudi Arabia, according to the World Health Organization (WHO) record. Heart disease deaths are almost 24% of the total deaths in Saudi Arabia in last few years. In the past years, wireless sensors have received increased attention due to their cost effectiveness, cheapness and small size when they are utilized in different environments [1-3]. A wireless sensor network (WSN) is used to monitor physical or

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environmental phenomena such as temperature, sound, pressure or motion and to pass the data through the network of sensors to a main location [4]. Also, they are used in many applications including military, health and home applications.

The ECG signal is a measure of the electrical activity of specialized heart cells, which generate repetitive self-induced action potentials. Each action potential generated will lead to contraction of the heart muscle and heartbeat.

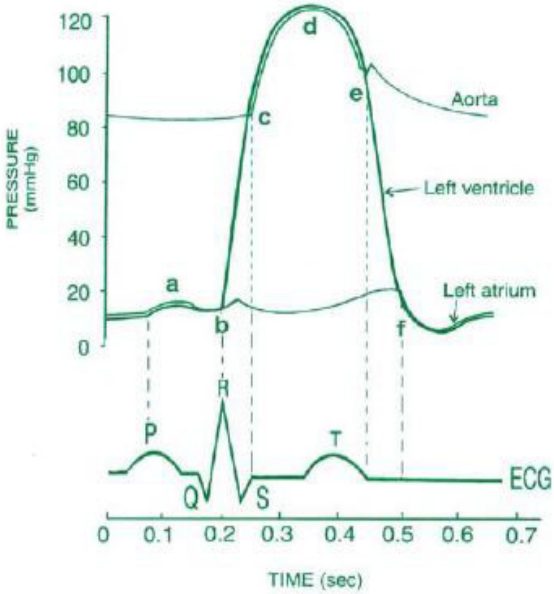

Fig. 1. Relation between the generation of a heartbeat and the pressure changes in the atria [5].

During each cardiac cycle, the atria and ventricles contract and relax to respectively pump and receive blood. Wiggers diagram, shown in Fig 1, provides a graphical explanation of the interactions between the electrical activity of the heart and the mechanical contractions of the heart chambers. The amplitude of the largest peak (R wave) is approximately one millivolt and the accepted frequency range for the ECG is between 0.05 Hz and 200 Hz. The accuracy of the signal depends on the resolution of the A/D converter used in the system. Most of the literature reflects the usage of 10 bit or 12 bit ADC [6], which in turn affects the accuracy.

The rest of the paper is organized as follows: section 2 illustrates the problem statement of this paper. Section 3 discusses some recent relevant woks while section 4 introduces the proposed system architecture. Section 5 discusses the system deployment and its performance analysis. The proposed system is analyzed in section 6 and the paper is concluded and future work in section 6.

2. Problem statement

In this paper we introduce a comprehensive real time monitoring ECG system that monitor patients inside and even outside the hospital, in his/her house. In this system we connect a Network WWSS on the patient body with a cluster head sensor which connects with the deployed WSNs on home or hospital. All recorded data using WWSS are transmitted via WSN the hospital. For any necessary action that needs to be taken in case of emergency, the hospital sends the data to the physician.

The proposed techniques should help in taking immediate responses with the medical staff to the patients. In certain situations, the patients are allowed to walk inside the hospital without any assistant and if sudden relapse happens, the location of patient can be easily determined using WSN address [7].

3. Previous work

There has been some work focusing on energy and power consumption in wireless sensor network. S. Cui et al. [8] studied the effect of different modulation techniques to minimize the consumption energy. The study of available total number of bits is considered in the given technique. The introduced technique gave 80% energy saving of WSN. A bit error rate and path loss as a function in frequency and sensor depth for different volumetric water content are introduced by I. Akyildiz et al. [9]. There are several challenges in the design of wireless underground communication network such as network topology, reliability, localization and network architecture design. A. Elleithy and G. Liu introduced an advanced model for power consumption calculation and optimization [10]. The effect distance, number of nodes, time of transmission, deployment area, and data bitrate are considered in this model.

Wireless sensor network (WSN) is a sensor used in monitoring physical or environmental conditions, such as temperature, sound, pressure, etc. [11]. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring [12]. A WSN is consisting of nodes, from a few to several hundred, where each node is connected to one or several sensors [13]. Each such sensor network node is consisting of a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting [14].

4. The proposed system architecture

The proposed system in this paper is using WWSS which is attached to the patient body with a cluster head sensor that communicate with the deployed WSNs on home or hospital. All recorded data using WWSS are transmitted via WSN to the monitoring system located on the hospital via internet. In case of emergency, the hospital sends the data to physician's cell phone for consultation. The physician can contact the patient directly for any instructions and the patient can also contact the physician for consultation. A detailed architecture of the proposed real-time monitoring ECG system is illustrated in Fig 2.

The main components of the proposed system are:

4.1. Wearable Wireless Sensor System (WWSS)

To be able to continuously sense the ECG signals of any patients, we used the wearable wireless sensor networks built on the patient body. WWSS has a lead chest electrodes sensor, interfacing and signal processing circuit, and the transmitter.

The lead chest electrodes will capture the signals from the heart and then will be amplified and filtered using the interfacing and signal processing circuit. The measuring signals will be directly transmitted to the local personal computer located at patient home and then to the internet, to a cell phone that support a software send the measured data to the internet if the patient is outside, or to hospital server in case that the patient is in the hospital and that data will be transverse to internet and to the control room in the hospital for any emergency action need to be taken. Local server will communicate with a physician and control room at the hospital for any needed action.

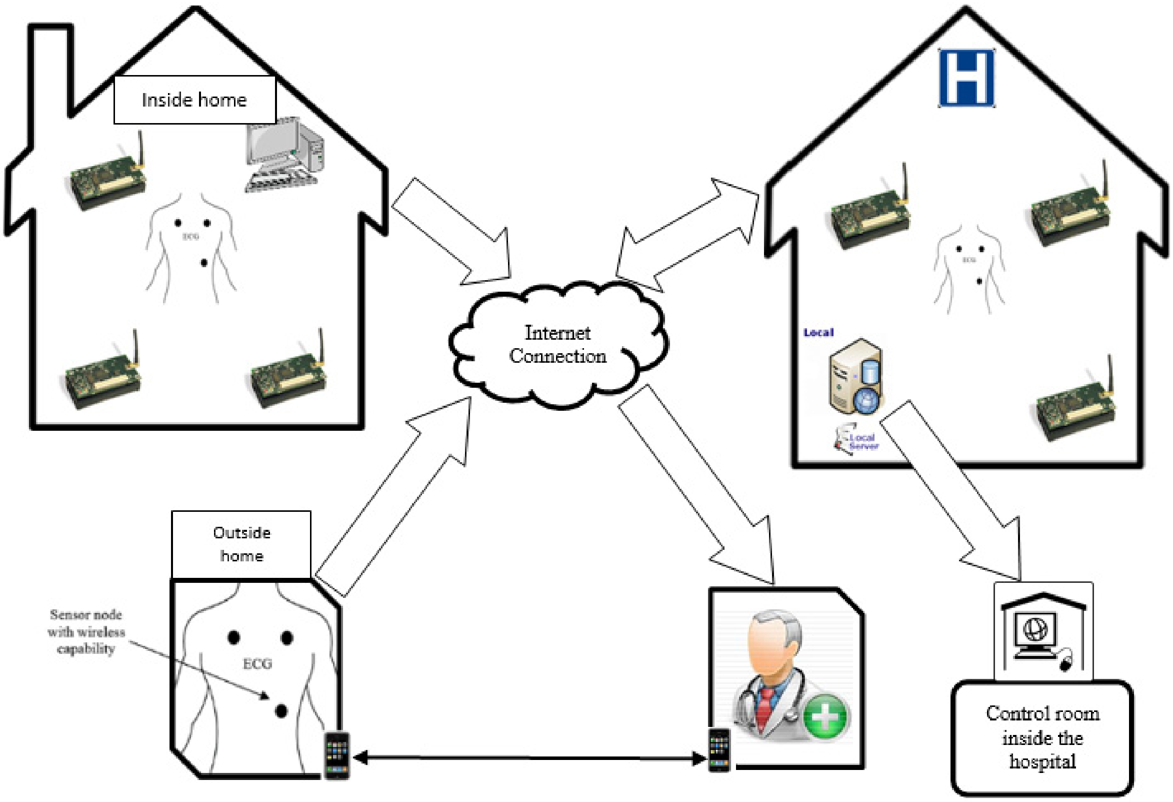

Fig. 2. Proposed system architecture.

4.2. Mobile Control System (MCS):

In case of the patient is outside his/her home or hospital, the connection will take a place with internet via cell phone. And then the transmitted data will be sent to the local server inside the hospital for needed action. In this case the location of a patient will be determining using GPS system that supported on patient mobile.

4.3. Local Server inside the hospital:

Local server has all needed database of all connect patient and a physician for each patient is assigned. Monitoring patients ECG signals will be carrying out in the local server and in case of any up normal condition, the given ECG signal will be transferred to control unit inside the hospital then the unit will send it to the assigned physician.

4.4. Warning System (WS):

In case of any emergency, the warning system will be ON and a warning action will be taken. The warning system is integrated in the mobile, local server, and in personal computer in the patient home.

5. System deployment and performance analysis

In the proposed system, WWSS are distributed on a patient body for continuous monitoring as shown in Fig 3. It can be seen that sensors are attached to a patient body either connected directly to his/her body or using a skirt with a built in WWSS.

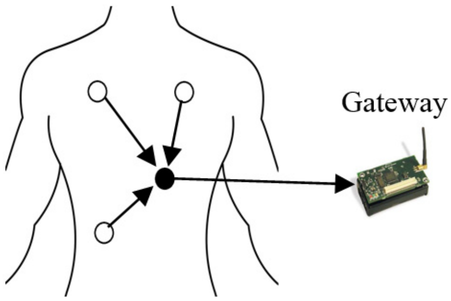

Fig. 3. Sensors distribution on a patient body.

5.1. WSN home implementation

In this section, the deployment of WSNs in the patient home is discussed. We assume that the patient home consists of three bedrooms, one living room, a bathroom, and a kitchen. Room size is assumed $4\times5\times3$ m^3, and the maximum kitchen and bathroom sizes are $3\times3\times3$ m^3. The maximum number of sensors needed to be installed in the patient home and the maximum allowable distance between sensors are investigated. The received power in an acceptable range is a crucial factor and is calculated as a function of the energy consumed in WSNs. The energy consumption of the deployed WSN in home and hospital and the received power as a function of distance between two wireless sensor networks are discussed.

5.2. Power, energy, and received power calculation

We present a model for energy and power consumption as a function of WSN distance, and SNR of the given system in order to be able to determine the required numbers of needed sensors. In this model, the total energy consumed in communications is given by Equation (1) [4]:

$$E = (P_t + P_{c0})\, T_{on} + P_{sp}T_{sp} + P_{tr}T_{tr} \tag{1}$$

where: P_t is the transmission signal power, P_{c0} is the circuit power consumption in the whole signal path, P_{sp} power consumption for the sleep mode, P_{tr} power consumption for the transient mode, T_{tr} is the transient mode duration, $P_{tr} \approx 2P_{syn}$, T_{sp} is the sleep mode duration, and T_{on} is the active mode time.

To calculate the P_{co} value, we need the mixer power consumption P_{mix}, the frequency synthesizer power consumption P_{syn}, the LNA power consumption P_{LNA}, the active filter power consumption P_{filt} at the transmitter, the active filter power consumption P_{filr} at the receiver, the IFA power consumption P_{IFA}, the DAC power consumption P_{DAC}, the ADC power consumption P_{ADC}, and the PA power consumption P_{amp}. P_{amp} can be calculated Equation (2).

$$P_{amp} = \alpha\, P_t \quad \text{and} \quad \alpha = (\xi/\eta) - 1 \tag{2}$$

where η is the drain efficiency and ξ is the peak-average power ratio (PAPR), which is dependent on the modulation scheme and the associated constellation size (3.01 dB for sine wave OFDM technique, and MQAM is given by $\xi = 3(M-2\sqrt{M}+1) / (M-1)$ and $M = 2^{L/BTon}$). P_{on} is the power consumption for the active mode and can be calculated using Equation (3):

$$P_{on} = \max\{ P_{on}, P_{tr}, P_{sp} \} \tag{3}$$

The peak-power constraints are given by Equation (4):

$$P_{ont} = P_t + P_{amp} + P_{ct} = (1+\alpha)\, P_t + P_{ct} \le P_{maxt}\; P_{onr} = Pcr \le P_{maxr} \tag{4}$$

where $P_{ct} = P_{mix} + P_{syn} + P_{filt} + P_{DAC}$
and $P_{cr} = P_{mix} + P_{syn} + P_{LNA} + P_{filr} + P_{IFA} + P_{ADC}$

In this model we neglect the start-up time for other circuit blocks and $P_c=P_{ct}+P_{cr}$. Hence, the energy consumption per information bit can be calculated using Equation (5):

$$E_a = E/L \tag{5}$$

And E_a is given by Equation (6):

$$E_a = [(1+\alpha)P_tT_{on} + P_cT_{on} + P_{tr}T_{tr}]/ L \approx [(1+\alpha)E_t + P_cT_{on} + 2\, P_{syn}\, T_{tr}]/ L \tag{6}$$

The bandwidth efficiency B_e can be calculated using Equation (7):

$$B_e = L/(B{*}T_{on}) \tag{7}$$

where B is the bandwidth of the transmitted package and L is the length of the package.

Hence the expression for the total energy consumption per bit at the receiver side is given by:

$$E_t = \frac{4}{3} N_f \sigma^2 (2^{\frac{L}{BT_{ON}}} - 1)\ln\left(\frac{4(1-2^{\frac{-L}{BT_{ON}}})}{\frac{L}{BT_{ON}}P_b}\right) G_d BT_{ON} \tag{8}$$

where N_f is the receiver noise fig, power spectral density of the AWGN, the k^{th} -power path loss factor $G_d = G_1 d^k M_l$ with d the transmission distance, M_l the link margin compensating the hardware process variations and other additive background noise or interference, and G_1 the gain factor.
To calculate the path loss, we used Equation (9).

$$Loss = \left(\frac{\lambda}{4\pi R}\right)^2 \tag{9}$$

Hence the received power can be calculated using Equation (10).

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \tag{10}$$

6. Results and discussion

In this section, we study the effect of transmitted power on the energy consumed per bit at the transmitter side, the total energy receiver at the receiver side, received power and SNR. The effect of distance on the power and energy performance of transmitting data from ECG system is also introduced in this section. All calculated data are given at both OFDM and MQAM modulation technique. Table 1 illustrates the simulation parameters.

Table 1. Simulation parameters used in the proposed system

Parameter	Value	Parameter	Value
B	10 kHz	T_{tr}	5 μsec
P_{mix}	30.3 mW	T	0.1 sec
P_{LNA}	20 mW	drainEff.	0.35
P_{maxt}	250 mW	L	2 kbit
k	3.5	G_l	30 dB
σ^2	-174 dBm/Hz	P_b	0.001
G_r	6 dBi	G_t	6 dBi
P_{syn}	50 mW	P_{filr}	2.5 mW
P_{IFA}	3 mW	N_f	10 dB
P_{filt}	2.5 mW	M_l	40 dB

6.1. Effect of transmitted signal power

The effect of changing the transmitting signal power of the wireless sensor network is given. The transmitted power range is taken from 50 μW to 10 mW at distance 1, 3, 5 m between sensors. The bit rate of the transmitted data is 10 kbps. Fig 4 shows the effect of changing transmission signal power, from 50 μW to 10 mW on the total power consumption. As clearly shown in Fig 4, the power consumption is increased from 440 mW to 500 mW as increasing transmitted signal power. Total energy consumption at the receiver side of WSN as a function of transmitted power is illustrated in Fig 5. The total energy consumption is varying in the range from 19 to 23 mJ.

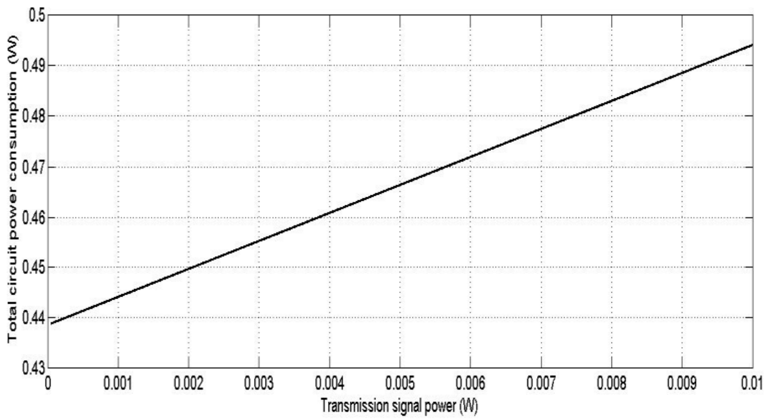

Fig 4. Total power consumption versus transmission power.

6.2. Effect of distance between sensors on the energy consumption

Total energy consumption as a function of distance between successive sensors is illustrated in Fig 6. The distance is varying between 1 m to 5 m and the total energy consumption is changing in a very high range to be a 0.12 μJ at 5 m distance. The transmission bit rate is 50 kbps and the transmitted power is 10 mW. Fig 7 shows the received power as a function of distance between two sensors.

6.3. Effect of changing transmission bit rate

Total energy consumption as a function of distance between successive sensors at 20 kbps and 100 kbps bitrate are illustrated in Fig 8 and 9 consequently. Increasing the bitrate will decries the total energy consumption and will increase the life time of the used sensors.

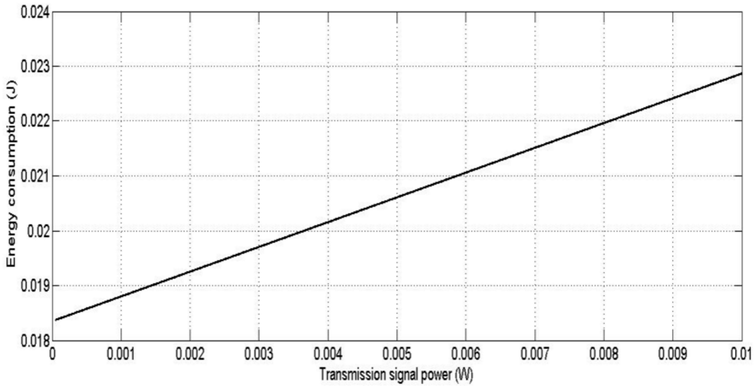

Fig 5. Energy consumption as a function of transmission power.

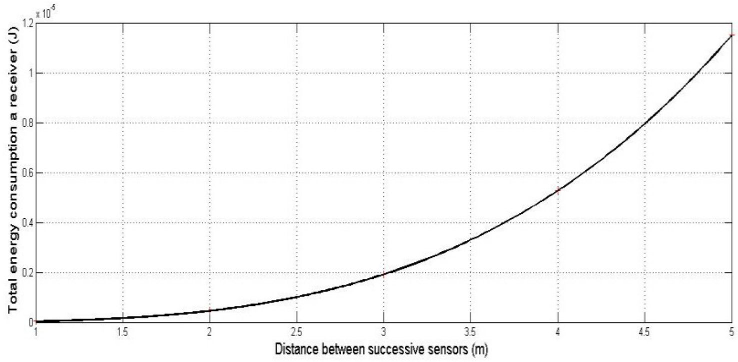

Fig 6. Total energy consumption (J) versus distance between successive sensors (m).

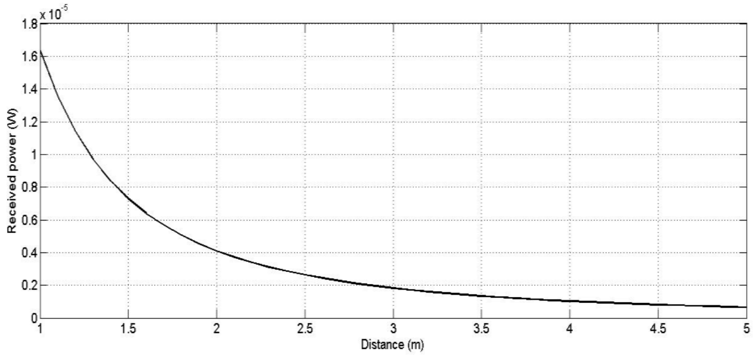

Fig 7. Total received power (W) versus distance between successive sensors (m).

In case of using MICAz module and according to the given datasheet, we can use only one sensor module in each room and at this case, we the distance between each module is 5 m [15]. The total output power from MICAz is 1 mW, at this situation the total power and energy consumptions are 0.445 W and 0.019 J respectively. Hence, the total energy consumption at 5 m distance is 12 µW and total received power is 0.08×10^{-5} W which means we still in save side for minimum received power for MICAz is 1 nW. Total received energy at 5 m distance and for 20 kpbs and 100 kbps are 3.5×10^{-6} J and 1.8×10^{-4} J respectively which means that increasing bit rate from 20 to 100 kbps is saving energy by 1.7×10^{-4} J. According to our calculations, the maximum number of sensors needed to be installed in the patient's home is 5 sensors.

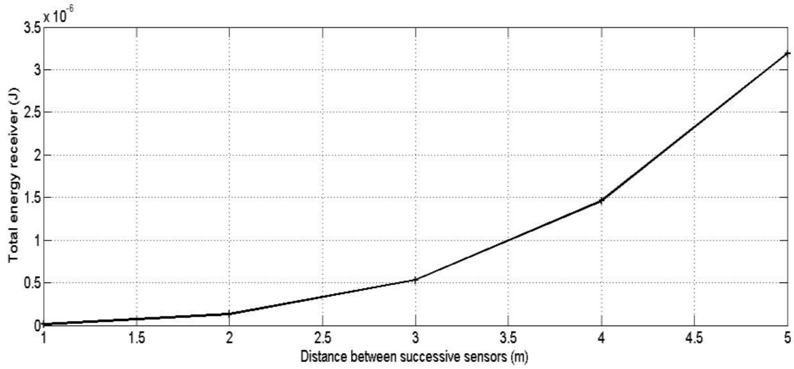

Fig 8. Total energy consumption (J) a function of distance between successive sensors (m) at 20 kbps.

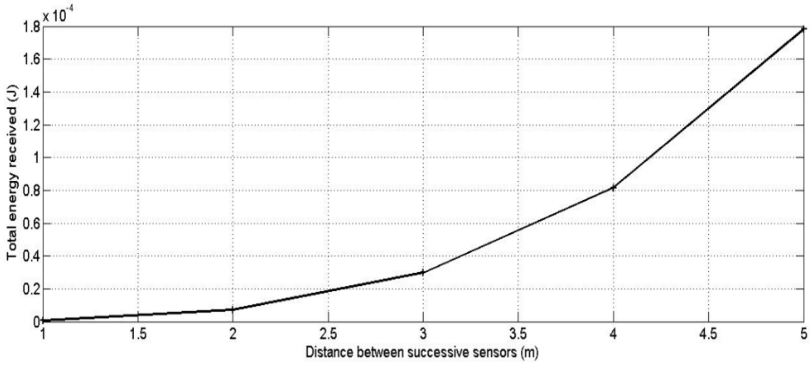

Fig 9. Total energy consumption (J) a function of distance between successive sensors (m) at 100 kbps.

7. Conclusion and future work

In the proposed system, we introduced a wearable real time monitoring ECG system for observing patients. We discussed the inside/outside system structure and study the effect of power and energy consumptions and optimum distance between WSN sensors on the designed system. We conclude that, by increasing the bit rate from 20 to 100 kbps an amount of 1.7×10-4 J will be saved and the installing 5 sensors in the patient's home is the optimum case that gives an optimum system performance.

In order to verify our proposed system we are going to apply the designed system on many cases and different hospitals. Also we are going to extend our system to be a fully monitoring system and 24/7 system.

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