A New Energy Efficient and Reliable MedRadio Scheme Based on Cooperative Communication for Implanted Medical Devices

Jen-Ming Hsu, Tzu-Chiang Chiang, Yao-Chang Yu, Wei-Guang Teng, and Ting-Wei Hou

1Department of Engineering Science, National Cheng Kung University, Tainan 701, Taiwan
2Department of Medical Information, Kaohsiung Medical University Hospital, Kaohsiung Medical University, Kaohsiung 807, Taiwan
3Department of Information Management, Tunghai University, Taichung 407, Taiwan
4TechKnowledge Services Group Inc., Taipei 104, Taiwan
5Department of Medical Informatics, National Cheng Kung University Hospital, Tainan 701, Taiwan

Correspondence should be addressed to Yao-Chang Yu; yuy0329@hotmail.com

Received 14 August 2014; Revised 28 September 2014; Accepted 16 October 2014

Copyright © 2015 Jen-Ming Hsu et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The most significant shortcoming of implanted devices is the battery life. With advanced technology, implanted devices can have the capability to communicate with other health-related devices, but this also means the energy consumption requirement is greater than ever. Less power consumption would extend the duration of the batteries of implanted medical devices. In this paper, an energy efficient and reliable communication service device scheme that does not require any modification to the existing wireless network structure or the implanted devices under consideration is proposed. The scheme is intended to save a target device's energy necessary for resending communication signals by introducing a neighbor group header node and cooperative (wearable) nodes. The simulation results show that the scheme would result in energy savings of 70 percent with one or two cooperative nodes as compared with the current best approach.

1. Introduction

The implant medical devices such as pacemaker, implantable cardiac defibrillator (ICD), neurostimulator system for deep brain stimulator, and insulin pump [1–4] are normally used to assist patients to maintain normal vital operation. Medical professions may need to monitor the implanted medical devices work as expected on patients; so the implanted devices would constantly transmit physiological signals back to medical data center for diagnosis. Many studies have proposed various solutions for inpatient monitoring and telemedicine [5–9]. The life of wireless implantable medical devices (IMDs) are usually limited by battery life. Additionally, besides supporting vital operation, the rest of the function provided by the implanted device is to handle the transmission of physiological signals. If the physiological signals received by the medical data center were incorrect or invalid, that would lead to incorrect diagnosis. Typically, IMD communicates with a receiver, which is a gateway to a remote server. Medical implant communication service (MICS) is a communication standard for medical and health care devices [10, 11]. An IMD adopts a MICS to communicate with a receiver, and the receiver will use a wired network to connect a server. The server stores long-term remote monitoring physiological IMD data. Medical staff give timely drug administration and treatments to an IMD wearer based on the wearer's stored data in the server. In addition, a medical professional can perform optimal adjustments to the operational parameters and dosages through wireless communication with an implanted device and can reduce the potential risks related to unexpected situations.

A typical installation that includes a wearer, a pacemaker, a receiver, and a server is shown in Figure 1. Currently most IMDs use an 802.15.6 [12] wireless body area network (WBAN) [13, 14] communication protocol. The 802.15.6 protocol follows the regulations on band definitions and
Table 1: Schematic overview of wireless technology in the medical application field.

| Wireless technology | WLAN | WPAN | LR-WPAN | WBAN |
|---------------------|------|------|---------|------|
| IEEE 802.11, Ex. Wi-Fi | IEEE 802.15.1, Ex. Bluetooth | IEEE 802.15.4, Ex. Zigbee | IEEE 802.15.6, Ex. MedRadio |
| Radio frequency spectrum | 5 GHz, 2.4 GHz | 2.4 GHz | 868 MHz, 915 MHz, 2.4 GHz | 401 to 406 MHz |
| Max. permitted power | 100 to 200 mW | 1 mW | 0.5 mW | 25 μW |
| Range | 100 to 250 M | 100 M | 10 M | 2 to 3 M |
| Max. transfer rate | 150 Mb/s | 24 Mb/s | 250 Kb/s | 10 Mb/s |
| Scope | On-body | On-body | On-body | In-body |

Table 2: Difference schemes for physiological monitoring.

| Varshney and Sneha [15] | Balasubramaniam and Kangasharju [16] | Proposed scheme |
|-------------------------|----------------------------------|-----------------|
| Communication pattern   | One-way end-to-end data collection (patient monitoring) | Two-way end-to-end communication (patient telemedicine) |
| Objective               | Avoid data loss and save ad hoc network power | Avoid data loss and save IMD power |
| Network configuration   | Conventional mobile ad hoc, and each node is equipped with a power management framework | Bulk sensor nodes Combination of cooperative communication and mobile ad hoc network |
| Diversity of simultaneous paths | One | One | Two or three |
| Power efficiency        | Low | Ultrahigh | High |

As an IMD is implanted in human body, wireless signal attenuation problems can occur [17, 18]. In order to solve the wireless signal attenuation problem, a number of solutions have been proposed in research on this topic [19–21]. A comparison between different schemes [15, 16, 22] is shown in Table 2.

In this research, a new scheme, called $E^2R$ MedRadio (Energy Efficient and Reliable MedRadio) is proposed. The proposed scheme is intended to introduce wearable devices that adopt a cooperative communication technique to help an IMD establish reliable communication and reduce retransmission. Due to the cooperative approach, the implanted device sends out physiological signal to communicate with multiple wearable devices by cooperative approach and forms diversity path to resist possible interference. When group header receives signal from multiple wearable devices, it selects signals with good reliability factor and sends the signals to the medical data center. Therefore, our proposed scheme will increase the reliability of signal transmission and reduce retransmission. On the other hands, if IMD communicates with wearable device through traditional ad hoc approach, there is only one path available at the time. When interference occurred during signal transmission, IMD has to continuously retransmit signal. Therefore, in order to ensure the quality and reliability of the signal transmission, our proposed scheme adopts cooperative approach. In the proposed scheme, the IEEE standard for local and metropolitan area networks-part 15.6: wireless body area networks is adopted as the international standard IEEE802.15. Task Group 6 to solve wireless personal area networks (WPANs) because the IEEE802.15.6 meets specific medical needs (proximity to human tissue) and supports applications that require reliability, QoS, low power, data rate, and noninterference.

In our scheme, the nodes are classified into IMD node ($I$ node), wearable or cooperative node ($W$ node), and group header node ($H$ node) according to communication capability and behavior. The cooperative communication technology ensures that the IMDs can properly transfer and receive the valid and current physiological or control signals to and from medical centers. In addition, the $E^2R$ MedRadio scheme defines a reliable communication evaluation index through the use of a power model, a signal strength model and weighting. Also, we proposed an algorithm to select the header node.
and cooperative nodes to make most of wireless channels that can be reused and prevent the IMD from retransmitting signals. Finally, the performance analysis of the proposed scheme is performed. The result of the simulations show the proposed scheme reduced power consumption up to 70 percent and that the reliability of signal transmission was increased by at least 11.7 percent. Therefore, the proposed scheme is suitable for use in the medical and healthcare environment to provide more energy savings and a reliable environment for implanted medical device communication.

In addition, this proposed scheme adopts the IEEE 802.15.6 and 802.11, which are already equipped with special secure communication capabilities; therefore, the proposed paper only focuses on communication reliability and energy consumption and does not include security issues.

2. $E^2R$ MedRadio Scheme and Mechanism

$E^2R$ MedRadio that requires no modification to IMD adopts the concept of cooperative communication [23, 24], and it is assumed to be used in wireless ad hoc network environments. A scenario for the proposed scheme is shown in Figure 2. The scenario shows that a patient with a pacemaker implanted comes back to the hospital for a checkup and/or setting of the IMD status. The IMD responds to the commands passed through MedRadio and returns data for physician interpretation and regular monitoring.

A patient will have one or two wearable devices, which may be in the form of a wrist-ring, a patch, or others. The reliability of communication can be enhanced by group communication, which is built into the mobile nursing cart and the nearby wearable (cooperative) nodes because they have more powerful energy and communication capabilities. The nearby wearable (cooperative) nodes are used to relay the communication signals for the header node and IMDs. The advantage of our proposed scheme is that the implanted device can have longer battery life due to the fact that fewer retransmissions are required. On the other hand, the power consumption of the wearable device is increased because the tables maintained by the wearable devices ($W$ nodes) can be frequently updated. However, this is an acceptable tradeoff because the wearable devices are much easier to recharge as compared with IMDs.

2.1. Assumptions. In order to make the proposed scheme work correctly, the following assumptions are required.

1. The IMD transmission range is limited to between 2 and 3 meters.
Node collects information from neighbors and build a group table (GT);
Powerful node ID node number decrease 100;
GT = {node 1, node 2, ..., node n};
if node ID == minimum element ID(GT) then
  /* serve as the group header */
  set group table flag = true;
  set H_flag = true;
  set GID = node ID;
  invite (table’s neighbor ID, self-node ID, GID);
end
else
  /* serve as a cooperative node */
  clear group table;
  clear GID;
  clear H_flag;
  receive invitation and group table form H;
end

Algorithm 1: Phase 0—initialization phase.

(2) Both wired and wireless communication infrastructure are required.

2.2. Cooperative Wireless Network Model. The nodes are divided into the following classes.

(i) I (IMD) node: an implantable medical device. This type of node is for implantation purposes (e.g., stabilizing the heartbeat), and its communication ability is limited to receiving and responding to commands from the receiver.

(ii) W (wearable or cooperative) node: a wearable device. This type of node is designed to receive/forward messages from/to the I node. It maintains a communication state list of where to send the received message.

(iii) H (group header) node: A W node elected by other W nodes in a group. Generally it is a node having higher computing and transmission capability.

Figure 3 depicts a simplified E²R MedRadio scheme by using the scenario described in Figure 2. The proposed scheme is divided into three phases. A brief description of each phase is provided as follows.

(1) Phase 0 (Algorithm 1) is the initialization phase. In this phase, all W nodes collect information of all neighbors and elect a header node.

(2) Phase 1 (Algorithm 2) is the join phase. In this phase, when a W node enters the communication zone, it receives invitations from groups and joins the existing group.

(3) Phase 2 (Algorithm 3) is the relay section phase. In this phase, the W nodes forward the message to their H node.

A more complicated scenario is shown in Figure 4. It is possible that H₁ and H₂ both receive same message, which is sent from the I₁ or I₂ via group 1 or group 2 members, W₁1, W₁2, W₂1, W₂2, and W₂3. For example, H₁ receives a message that is sent from I₁ through W₁1, and H₂ receives exactly the same message that is also sent from I₁ through W₂1. When H₁ and H₂ receive the message, they both send the message to the medical data center. The medical data center only accepts the message that comes in first and discards the message that arrives later.

2.3. Algorithm Description. The proposed scheme includes three algorithms for which flow chart in Figure 5 and a detailed description is provided as follows.
(1) Node receives information from neighbors \( H \) and record to itself GT;
(2) while \( \text{Time-to-Live} > 0 \) do
(3) receive invitation \((H, ID, GID)\);
(4) if \( HID = GID \) then
(5) Add \( HID \) to GT;
(6) end
(7) end
(8) if \( GT \neq \text{NULL} \) then
(9) chose minimum \( HID \) from GT;
(10) send join message and self-node ID;
(11) if \( \text{last} \_GID \neq \text{NULL} \) then
(12) Send leave node ID, Last_GID;
(13) end
(14) set GID = \( HID \);
(15) set Last_GID = \( HID \);
(16) end
(17) Restart Initial Phase;

Algorithm 2: Phase 1—join phase.

(1) Receive \((W, ID, W\_RELI\_F, WIMD)\);
(2) if \( WIMD \neq \text{NULL} \) then
(3) if \( RELI\_F > 3rd\_RELI\_F \) then
(4) update GT;
(5) update current allow \( W(W, ID, W\_RELI\_F, WIMD)\);
(6) forward physiological signal;
(7) chose maximum \( W\_RELI\_F \) from GT;
(8) change \( H \);
(9) end
(10) else
(11) drop message;
(12) end
(13) end
(14) else
(15) update GT;
(16) update current allow \( W(W, ID, W\_RELI\_F, WIMD)\);
(17) end

Algorithm 3: Phase 2—relay selection phase.

In phase 0, each node first builds a group table (GT) for itself and then collects neighboring nodes’ information to record the information into GT. After GT is established in each node, then all nodes participate in electing the \( H \) node. In this phase, in order to quickly form groups and have a header node to manage the group, GT only contains the ID for \( W \) nodes, and GT is sorted by the node ID in ascending order.

The node with smallest ID elected the \( H \) node and the node ID is group ID (GID). After the \( H \) node election, the elected \( H \) node broadcasts GT with its node ID listed on the top to all \( W \) nodes within the group in order to synchronize the GT.

After phase 0, which means groups are formed, and the \( H \) node is selected in each group, within each group, each \( W \) node sends a reliability factor to \( H \) node, and \( H \) node records all reliability factors from all \( W \) nodes into GT. The \( H \) node synchronizes GT that contains the \( W \) nodes’ ID and reliability factors to all \( W \) nodes in the group. Now, the \( W \) node with the highest reliability factor becomes the \( H \) node and resorts the GT according to the reliability factor in descending order. Then, the \( H \) node broadcasts the GT to all \( W \) nodes in the group. Selecting the node with highest reliability factor ensures the communication reliability.

In addition, each \( W \) node in the group maintains its own WIMD table, which records reachable IMD IDs and IMD reliability factors. All WIMD tables from all \( W \) nodes are sent to the \( H \) node in the group. When WIMD table is updated, the \( W \) node sends it to the \( H \) node for synchronization. In summary, within a group, each \( W \) node owns a WIMD table and is responsible for maintaining the WIMD table. Each \( H \) node owns \( n \) (the number of \( W \) nodes) WIMD tables and one GT. The \( H \) node is responsible for maintaining the GT.
In phase 1, because there is a group, if a node moves into the communication range of the $H$ node, the node waits for an invitation for a time-to-live (TTL) period. If there are multiple invitations, then it selects the invitation from the one with the minimum header ID ($H_{ID}$) to join the group. On the other hand, if the node does not receive any invitations, the initial phase will restart again until the node either joins an existing group or becomes a one-node group by itself. Because the group forms an ad hoc network, all $W$ nodes, are either in the initial phase or the join phase.
When an $H$ node leaves or fails, other group members will remove the $H$ node information from the GT, and the second node on the GT will be designated as the new $H$ node of the group. In the worst case, if this newly selected $H$ node still fails, then this group enters the initialization phase to select the $H$ node instead of designating the third node on the GT to be the $H$ node.

In phase 2 (relay selection phase), algorithm phase two is invoked. Two or three $W$ nodes for relaying messages are chosen for the $I$ node. The $H$ node collects information including the ID of the $W$ node ($W_{ID}$), as well as the reliability factors ($W_{RELI}$), and WIMD table for the $W$ node.

If the $W$ node’s WIMD table is not "NULL," then the $H$ node checks the reliability factors to see whether the $W$ node’s reliability factor can be listed on the top three in the GT. If yes, then the $H$ node updates the $W$ node reliability factor in the GT and resorbs the GT based on the value of the reliability factor. The three $W$ nodes listed on the top three in the GT are the nodes selected to relay messages of physiological signal. If no, the $W$ nodes’ messages will be dropped and also the $H$ node updates the $W$ node reliability factor in the GT even $W$ nodes reliability factor without top 3. In addition, if the reliability factor of the $W$ node turns out to have the highest reliability factor, it means this $W$ node is listed on the first in GT, and then the $W$ node is assigned as the header in the group. When the $W$ node becomes the $H$ node, it updates its GT and broadcasts the GT to all $W$ nodes in the group. On the other hand, if the collected $W$ node has an empty WIMD table, then this $W$ node updates its reliability factor to the GT.

Each $H$ node constantly sends message to all $W$ nodes in the group to check availability of all $W$ nodes. If $H$ node does not receive any response from $W$ nodes in TTL (time-to-live) period, $H$ node deletes nonexisting $W$ nodes from the GT and then broadcasts the new GT to all available $W$ nodes. Hence, when a $W$ node moves out of the group communication range that means the $W$ node is not able to receive or respond checking message from $H$ node, so the $H$ node considers this $W$ node is no longer available and deletes it from the GT.

2.4. Reliability Factor. An agent collects the reliability factors of its neighboring cooperative nodes to coordinate the transmission sequence at the cooperative period. In order to choose a reliable cooperative node, the reliability factor plays an important role of selecting proper node to rely signals. Reliability factor ($F_r$) is defined and calculated as follows:

$$
F_r = W \left( P_{i}^{rem} \times C_{i}^{signal} \right).
$$

The $W$ represents the statistical weight (between 0 and 1) and is introduced to avoid the issue of continual transmission error while a node’s power and channel are still good.

$P_{i}^{rem}$ represents the remaining power (ranging from 0 to 1) of a node $i$, as defined in (2), and $C_{i}^{signal}$ represents the signal strength of the node $i$. $P_{i}^{rem}(t-1)$ is the power status of last transmission, and $P_{i}^{buy}(t-1, t)$ is the power consumed during the last transmission. Consider the following:

$$
P_{i}^{rem} = P_{i}^{rem}(t - 1) - P_{i}^{buy}(t - 1, t).
$$

The power management is assumed to be performed by an agent installed in each node. Referring to Biradar and Manvi [25], the proposed scheme also provides assessments to the surrounding nodes. In addition, the following equation is introduced to assess the signal strength of a communication channel:

$$
C_{i}^{signal} = K \left( S_{j}^{IMD}(t) - S_{j}^{IMD}(t - 1) \right),
$$

where $C_{i}^{signal}$ represents the last transmitted signal that is received by the cooperative node $i$. The cooperative node that assesses and analyzes the IMD node $j$ signal strength and channel condition can be regarded as SNR. $K$ is the proportionality constant to restrict $C_{i}^{signal}$, ranging from 0 to 1. $S_{j}^{IMD}(t)$ indicates most recent period during which the cooperative node received SNR from an IMD node $j$. $S_{j}^{IMD}(t-1)$ indicates before the most recent period the cooperative node to receive SNR from IMD node.

At some point in time, the signal strength shows the following equation, where $E_{i}$ is the transmission power and where $N_{0}$ represents the noise strength:

$$
S_{j}^{IMD} = \frac{E_{i}}{N_{0}}.
$$

3. Example

Figure 6 illustrates how the delivery path for a message is selected. Figure 6(a) shows the IMD sending path. In Figure 6(b), wearable nodes $W_{11}$ and $W_{12}$ in group 1, $W_{21}$ in group 2 receive the message from node $I_{1}$. In Figure 6(c), header nodes $H_{1}$ and $H_{2}$ receive the message from their members. In this case, $H_{1}$ selects $W_{21}$, and $H_{2}$ selects $W_{21}$ to forward the message.

As shown in Figure 7, the same information will be forwarded from the $I$ node. In the $H$ node, an agent coordinates the delivery sequence by referring to a group table for each independent diversity path. In a steady state, $H$ node uses a control message to exchange the group table with wearable nodes. In phase 1, wearable nodes receive data from $I$ node. And wearable nodes forward data to header node in phase 2. The path for an IMD sending a message to the $W$ or $H$ node can have at most three possible independent paths, and vice versa, for the medical center sending control messages to the IMD. This implies that the cooperative nodes require only half-duplex communications, but dual antennas can be used to send and receive messages simultaneously.

4. Performance Evaluation

In order to make a comparison with the conventional ad hoc, a ward environment with a patient who is implanted with an IMD is simulated using NS2. The parameters are
Figure 6: Illustrates how our scheme selects a message delivery path. (a) IMD sending path; (b) cooperative relay path; (c) reliability message path.
Figure 7: Reliable and diversity transmission route path.

Figure 8: The impact of cooperative nodes is diversity and reliability.

4.1. Reliability. We use $\text{Prob}_{\text{success}} = 1 - \alpha$ to evaluate the reliability in the steady state, where $\alpha$ is the communication failure rate from the access point to an IMD node, considering all possible paths. Therefore $\alpha$ can be derived from the following equation:

$$\alpha = \prod_{k=1}^{m} \left(1 - P_{AP \rightarrow GH_k}\right) \prod_{i=1}^{n} \left[1 - (P_{GH \rightarrow R_i} \ast P_{R_i \rightarrow D})\right],$$

(5)

where "k" denotes the number of paths. This notation "$AP \rightarrow GH_k$" represents the path from an access point to a group header node that routes to some destination IMD node. Therefore the "$P_{AP \rightarrow GH_k}$" represents the successful transmission probability of an access point to a group header node. "i" denotes the number of relay paths. "$P_{GH \rightarrow R_i} \ast P_{R_i \rightarrow D}$" denotes the successful probability from some specific group header node via some cooperative nodes (relay) to some specific IMD node.

In Figure 8, the simulation results show that the proposed scheme exhibited higher reliability than the conventional ad hoc scheme by over 11.7%, when there were more than two nodes in an IMD’s range. Therefore, two or three cooperative nodes are enough to fulfill the reliability requirement of wireless communication. In our simulation, the results indicate...
that the best result is achieved when an IMD is surrounded with more than three W nodes.

4.2. Power Consumption. Figure 9 shows the power consumption for different paths when there are three cooperative nodes in the range of an IMD. The proposed scheme consumes 1 unit of power but the conventional ad hoc consumes 0.6 units more than the proposed scheme due to signal retransmission. In the simulated cases, the proposed scheme reduces energy demand by up to 70% in the best case.

5. Conclusion

In medical and healthcare environments, IMDs are usually suitable for signal delivery rather than for information processing. By using the reliability factor to select a highly reliable cooperative node for relaying signals, the proposed scheme significantly reduces the number of signal retransmissions as compared with the conventional ad hoc network technology. In addition, a hierarchical multipath and cooperative communication technology are used to overcome insufficient bandwidth and delay problems. The simulation results suggest that 1 to 3 cooperative (relay) nodes are sufficient. Therefore, the proposed scheme helps IMDs consume less power and improve IMD battery life.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

The research was partially supported by National Science Council, under Project NSC102-2221-E-006-138.

References

[1] O. Erdogan, “Electromagnetic interference on pacemakers,” Indian Pacing and Electrophysiology Journal, vol. 2, no. 3, pp. 74–78, 2002.
[2] O. S. Pantchenko, S. J. Seidman, J. W. Guag, D. M. Witters Jr., and C. L. Sponberg, “Electromagnetic compatibility of implantable neurostimulators to RFID emitters,” BioMedical Engineering Online, vol. 10, article 50, 2011.
[3] W. Kainz, F. Alesch, and D. D. Chan, “Electromagnetic interference of GSM mobile phones with the implantable deep brain stimulator, TREL-III,” BioMedical Engineering Online, vol. 2, article 11, 2003.
[4] B. Houlston, D. Parry, C. S. Webster, and A. F. Merry, “Interference with the operation of medical devices resulting from the use of radio frequency identification technology,” The New Zealand Medical Journal, vol. 122, no. 1297, pp. 9–16, 2009.
[5] M. M. Baig and H. Gholamhosseini, “Smart health monitoring systems: an overview of design and modeling,” Journal of Medical Systems, vol. 37, no. 2, article 9898, 2013.
[6] C.-F. Lin, “Mobile telemedicine: a survey study,” Journal of Medical Systems, vol. 36, no. 2, pp. 511–520, 2012.
[7] K.-Y. Chen, F.-G. Chen, and T.-W. Hou, “A low-cost reader for automatically collecting vital signs in hospitals,” Journal of Medical Systems, vol. 36, no. 4, pp. 2599–2607, 2012.
[8] S.-K. Chen, T. Kao, C.-T. Chan et al., “A reliable transmission protocol for zigbee-based wireless patient monitoring,” IEEE Transactions on Information Technology in Biomedicine, vol. 16, no. 1, pp. 6–16, 2013.
[9] H. Ali, A. P. Lobo, and P. C. Loizou, “Design and evaluation of a personal digital assistant-based research platform for cochlear implants,” IEEE Transactions on Biomedical Engineering, vol. 60, no. 11, pp. 3060–3073, 2013.
[10] Federal Communications Commission, “FCC-99-363, Amend Rules to Establish a Medical Implant Communications Service in the 402–405 MHZ Band,” 1999, http://transition.fcc.gov/Bureaus/Wireless/Orders/1999/fcc99363.txt.
[11] Federal Communications Commission, “FCC-06-103A1, Investigation of the Spectrum Requirements for Advanced Medical Technologies,” 2006, https://apps.fcc.gov/edocs_public/attachmatch/FCC-06-103A1.pdf.
[12] The Institute of Electrical and Electronics Engineers, IEEE Standard for Local and Metropolitan Area Networks-Part 15.6: Wireless Body Area Networks, IEEE, 2012, http://standards.ieee.org/getieee802/download/802.15.6-2012.pdf.
[13] S. Ullah, H. Higgins, B. Braem et al., “A comprehensive survey of wireless body area networks on PHY, MAC, and network layers solutions,” Journal of Medical Systems, vol. 36, no. 3, pp. 1065–1094, 2012.
[14] B. Latre, B. Braem, I. Moerman, C. Blondia, and P. Demeester, “A survey on wireless body area networks,” Wireless Networks, vol. 17, no. 1, pp. 1–18, 2011.
[15] U. Varshney and S. Neche, “Patient monitoring using ad hoc wireless networks: reliability and power management,” IEEE Communications Magazine, vol. 44, no. 4, pp. 49–55, 2006.
[16] S. Balasubramaniam and J. Kangasharju, “Realizing the internet of nano things: challenges, solutions, and applications,” Computer, vol. 46, no. 2, pp. 62–68, 2013.
[17] R. Chávez-Santiago, K. E. Nolan, O. Holland et al., “Cognitive radio for medical body area networks using ultra wideband,” IEEE Wireless Communications, vol. 19, no. 4, pp. 74–81, 2012.
[18] B. Hegyi and J. Levendovszky, “Enhancing the performance of medical implant communication systems through cooperative diversity,” *International Journal of Telemedicine and Applications*, vol. 2010, Article ID 920704, 10 pages, 2010.

[19] K. Sayrafian-Pour, W.-B. Yang, J. Hagedorn, J. Terrill, and K. Y. Yazdandoost, “A statistical path loss model for medical implant communication channels,” in *Proceedings of the IEEE 20th Personal, Indoor and Mobile Radio Communications Symposium (PIMRC ’09)*, pp. 2995–2999, Tokyo, Japan, September 2009.

[20] R. Chavez-Santiago, K. Sayrafian-Pour, A. Khaleghi et al., “Propagation models for IEEE 802.15.6 standardization of implant communication in body area networks,” *IEEE Communications Magazine*, vol. 51, no. 8, pp. 80–87, 2013.

[21] J. Abouei, J. D. Brown, K. N. Plataniotis, and S. Pasupathy, “Energy efficiency and reliability in wireless biomedical implant systems,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 15, no. 3, pp. 456–466, 2011.

[22] S. Sneha and U. Varshney, “A framework for enabling patient monitoring via mobile ad hoc network,” *Decision Support Systems*, vol. 55, no. 1, pp. 218–234, 2013.

[23] A. Nosratinia, T. E. Hunter, and A. Hedayat, “Cooperative communication in wireless networks,” *IEEE Communications Magazine*, vol. 42, no. 10, pp. 74–80, 2004.

[24] Y. Chen, F. Qin, Y. Xing, and D. Buranapanichkit, “Cross-layer optimization scheme using cooperative diversity for reliable data transfer in wireless sensor networks,” *International Journal of Distributed Sensor Networks*, vol. 2014, Article ID 714090, 16 pages, 2014.

[25] R. C. Biradar and S. S. Manvi, "Neighbor supported reliable multipath multicast routing in MANETs," *Journal of Network and Computer Applications*, vol. 35, no. 3, pp. 1074–1085, 2012.

[26] European Telecommunications Standards Institute, *Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Radio Equipment in the Frequency Range 402 MHz to 405 MHz for Ultra Low Power Active Medical Implants and Accessories; Part 1: Technical Characteristics, Including Electromagnetic Compatibility Requirements, and Test Methods*, European Telecommunications Standards Institute, Sophia Antipolis, France, 2002, http://www.etsi.org/deliver/etsien/301800301899/30183901/01.01.0160/en30183901v010101p.pdf.
Submit your manuscripts at
http://www.hindawi.com