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Reliable Wireless Patient Monitoring System Using Hybrid Transmission Protocol

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Abstract: The fast-growing global elderly population increases demands for caretaking, which has resulted in increasing importance of patient monitoring system. These systems can use wireless technologies to transmit vital signs for medical evaluation. The existing system use broadcast or multicast to improve reliability but this leads to higher network traffic and delay. In this paper, we present a reliable transmission protocol based on anycast routing for wireless patient monitoring. Our scheme automatically selects the closest data receiver in an anycast group as a destination to reduce the transmission latency as well as the control overhead. The new protocol also shortens the latency of path recovery by initiating route recovery from the intermediate routers of the original path. On the basis of a reliable transmission scheme, we a ZigBee device for fall monitoring, which integrates fall detection, indoor positioning and ECG monitoring. When the triaxial accelerometer of the device detects a fall, the current position of the patient is transmitted to an emergency center through a ZigBee network. In order to clarify the situation of the fallen patient, 4-s ECG signals are also transmitted. Our transmission scheme ensures the successful transmission of these critical messages. The proposed system can seamlessly integrate with the next generation technology of wireless wide area network, worldwide interoperability for microwave access, to achieve real-time patient monitoring.

Key words: Anycast · Broadcast · ECG · Multicast · Patient monitoring · Vital sign sensor · Worldwide interoperability for microwave access (WiMAX) · ZigBee

INTRODUCTION

The changes brought about by the aging society include an increasing demand for caretaking; thus, patient monitoring systems are gaining their importance in reducing the need for human resources. Vital signs, such as body temperature, blood pressure and sugar level, can be regularly collected and remotely monitored by medical professionals, achieving a comprehensive caretaking system. The transmission of vital signs in nursing homes and hospitals is usually carried out wirelessly. The regularly collected information can be stored and transmitted in a given time period, the emergency messages must be transmitted immediately [1]. The transmission path of vital signs can be divided into outdoor and indoor. The technology of wireless wide area networks (WWANs) is used for outdoor transmission and that of wireless mesh network (WMN) is responsible for indoor transmission. Long term evolution (LTE) and worldwide interoperability for microwave access (WiMAX) technologies will greatly improve the quality of patient monitoring since the vital signs can be transmitted with better bandwidth management [2].

For the indoor transmission of vital signs, WMN is a convenient technology, which can dynamically establish a multihop network topology without prior configuration. The WMN devices could change locations and configure itself on the fly. They are also widely adopted for indoor positioning. These devices have advantages of power efficiency, low cost and small volume and size. ZigBee is an open standard technology to address the demands of low-cost, low-power WMNs via short range radio. ZigBee is targeted at RF applications that require a low data rate, long battery life and secure networking. The ZigBee devices can be combined with WWANs to achieve a seamless platform of wireless patient monitoring.

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Table 1: Transmission Modes

Property \ Mode	Unicast	Multicast	Broacast	Anycast
Communication Mode	One to One	One to Many	One to All	One to Any
Membership	Single	Multiple	Multiple	Multiple
Destination	Node	Group	All	Group

In this paper, we present a reliable protocol of packet forwarding that transmits emergency messages with vital signs on a multihop ZigBee network. We deploy multiple data sinks in a ZigBee network. Our protocol uses anycast to find the nearest available data sink. When the path to the original data sink fails, our protocol automatically selects another data sink as the destination. The transmission path is rebuilt from the last node before the failure link; hence, the latency of path recovery is shorter than that for the unicast-based approaches that must rebuild a path from source node [3]. As compared with multicast/ broadcast approaches, our protocol significantly reduces the traffic overhead while maintaining the reliability at the same level. With our reliable transmission protocol, we implement a ZigBee device for fall monitoring, which integrates fall detection, indoor positioning and ECG monitoring. When the triaxial accelerometer of our device detects a fall, the current position of the patient is generated and transmitted to a data sink through a ZigBee network. In order to clarify the situation of the fallen patient, 4-s ECG signals are transmitted along with the emergency message [4].

Our paper is organized as follows. Section II provides a brief discussion on communication modes and the previous work on mobile healthcare systems. Section III describes the reliable transmission protocol, followed by the fall monitoring system in Section IV. The simulation results are shown in Section V. Section VI presents our conclusions.

Related Work

Communication Modes: Data transmission can be categorized into four modes, namely, unicast, multicast, broadcast and anycast. Both multicast and broadcast are one-to-many transmission, but multicast communication must specify the address of the multicast group to identify the potential receivers. Since multicast and broadcast can deliver messages to multiple receivers, they are suitable for the applications demanding stringent data integrity. Nevertheless their weakness stems from the large number of packets that may impede the transmission rate. Unicast differs from previous two modes in that it delivers packets only to a single receiver. Unicast transmission has the least traffic overhead; however, when the path to the receiver fails, additional procedure of path recovery must be carried out to find another receiver. Table 1 shows the properties of various transmission modes [5].

Anycast is a new network routing approach in which messages from a sender are routed to the topologically nearest receiver in a group of potential receivers. The group is called an anycast group and the receivers in the same anycast group are identified by the same anycast address. Anycast also has better reliability than unicast since it is capable of selecting a new receiver

Wireless Patient Monitoring Systems: In wireless patient monitoring system, the previous schemes tend to use broadcast or multicast schemes to achieve reliable message delivery in a multihop wireless network. However, the cost of network traffic is also significantly increased. Although the number of transmission hops and traffic overhead can be reduced by using excess transmission power, the collision domain is also enlarged to severely degrade the transmission efficiency of MAC layer [6]. Therefore, in our system we combine anycast with a reliable transmission mechanism to improve the efficiency of message transmission in this paper. Since our scheme does not rely on increasing transmission power, the power efficiency of our scheme can be improved as well.

Reliable Transmission Protocol: In our network architecture, we categorize the nodes into three types: sensor, router and data receiver. The sensor node acquires vital signs and encapsulates these data in packets. Then, the sensor node transmits packets to a data receiver through the closest router. We assume that the sensor node is mobile. Thus, the path to the data receiver would consistently change. Router node is responsible for forwarding messages to a data receiver. Since we use an anycast routing protocol, the data receiver is the nearest one. The data receiver node acts as a data sink, which collects physiological information and transmits to the medical or emergency center. As mentioned previously, the data receiver node can be combined with WWAN technologies, such as LTE or WiMAX, to achieve a seamless platform of wireless patient monitoring [7]. We depict the architecture of our platform in Fig. 1. In our platform, the router nodes form a multihop WMN.

To ensure successful transmission in the WMN, we propose a reliable transmission protocol based on the ad hoc On-Demand Distance Vector (AODV) routing protocol. The AODV routing protocol is an on demand

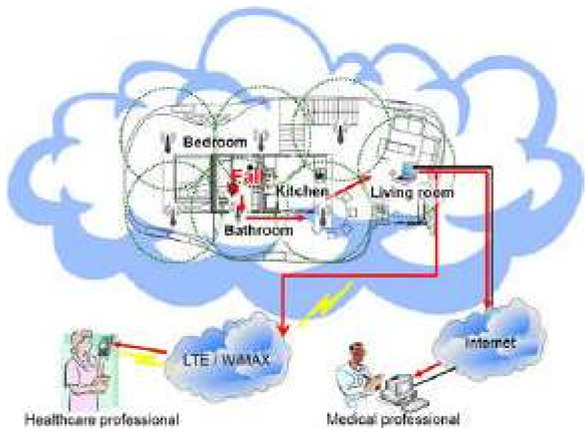

Fig. 1: Architecture of our wireless patient monitoring system.

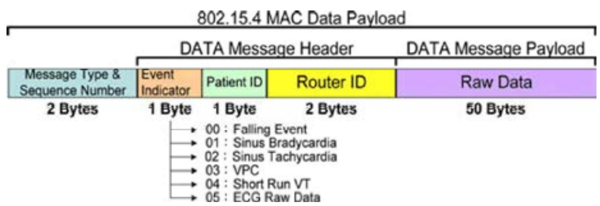

Fig. 2: DATA message format in the 802.15.4 MAC data payload.

algorithm, which builds routes to the destination only as desired by source nodes. There are two types of packets, route request (RREQ) and route reply (RREP), used in the route establishment. When a source node attempts to communicate with a destination whose route is unknown, it broadcasts an RREQ packet across the network. The RREQ contains the address of the source node, current sequence number, broadcast identifier and the most recent sequence number for the destination of which the source node is aware. Nodes receiving an RREQ update their information for the source node and set up backward pointers to the source node in their routing tables. A node receiving an RREQ sends an RREP if it either is the destination or has a route to the destination. The RREP is sent to the source by using unicast. Otherwise, the router node rebroadcasts the RREQ to its neighbours [8]. Each node keeps track of the RREQ's source address and broadcast identifier. If a receives an RREQ which it has already processed, it simply ignores the RREQ. As the RREP propagates back to the source, nodes receiving the RREP set up forward pointers to the destination in their routing tables. Once the source node receives the RREP, it begins to forward data packets to the destination. Each node could update its routing information for a destination if it receives an RREP with a smaller hop count. The route is kept in the routing table as long as it is needed. AODV also uses sequence numbers to ensure the freshness of routes. If a link failure of an active route occurs, the node upstream of the break propagates a route error (RERR) message to the source node to notify the event of an unreachable destination. After receiving the RERR, the source node reinitiates route discovery to resume data transmission [9].

AODV has the advantages of loop-free, self-starting and scalability. However, AODV cannot ensure the reliability of the transmitted data. Therefore, we improve the reliability of AODV by introducing the capability of anycast routing. In addition, we deploy multiple data receivers in a WMN. With the anycast routing, the source node can communicate with the closest data receiver. We further use a hybrid approach that combines the mechanism of reliable data transmission with anycast routing to achieve efficient route recovery.

Our protocol has five message types, including RREQ, RREP, RERR, DATA and acknowledgment (ACK). The first three messages, RREQ, RREP and RERR, are inherited from AODV and are used to maintain the routing information. The DATA message is only transmitted after an active route to the data receiver is discovered [10]. When the data receiver receives a complete DATA message, it sends an ACK message back to the source node. We show the format of our DATA message in Fig. 2, where the DATA message is stored in the 802.15.4 MAC data payload.

Sensor Node: In a sensor node, there are two modules: sensor and ZigBee. Both modules are connected through an RS-232 interface. The patient or elder is equipped with a sensor node to acquire vital signs from the sensor module. The vital signs are then encapsulated in packets and transmitted by the ZigBee module. Since a sensor node is mobile, the path to the data receiver could change arbitrary. Each ZigBee module has a *DataReceiver* list to store the addresses of the data receivers notified from the received RREP messages and the next hops to the corresponding data receivers.

The operations of a sensor node are described as follows.

When a sensor module acquires vital signs, it informs the ZigBee module to check whether it has the route information to the data receiver. If *yes*, then the ZigBee module transmits packets to a data receiver. Otherwise, the ZigBee module encapsulates an RREQ message into a frame and broadcasts the frame to the neighbouring router nodes. When the ZigBee module receives an RREP packet, it adds route record to its routing table for the data receiver. If the ZigBee module receives more than one RREP packet, the data receivers specified in the extra RREP packets are stored in the *DataReceiver* list. With an active route, the sensor module could periodically sample vital signs and store these data in the buffer of the ZigBee module. Once the buffer of the ZigBee module is full, the ZigBee module encapsulates the data into a DATA message for transmission. After sending a DATA message, the ZigBee module periodically checks the ACK message from the data receiver. When the ZigBee module receives an ACK message, it removes the acknowledged data. If the ZigBee module receives an RERR message or the ACK message is not received within a timeout period, it checks its *DataReceiver* list. In the case that the *DataReceiver* list is not empty, the first entry in the *DataReceiver* list is retrieved and inserted into the routing table. The DATA message is then retransmitted to the new data receiver. If the *DataReceiver* list is empty, then the ZigBee module will retransmit RREQ packet to discover a new route.

Router Node: The router node provides the functions of route maintenance and packet relaying; hence, it only has a ZigBee module. When a router node receives an RREQ packet, it checks whether it has the route record for the queried destination node. If *yes*, then it replies with an RREP message to the sensor node. Otherwise, the RREQ message is rebroadcasted to its neighbours. Each router node uses a counter, *AnycastGate*, to record the number of the received RREP messages. The counter also indicates the number of data receivers, which can be contacted through the router node. The router node also has a *DataReceiver* list for storing the data receivers notified from the received RREP messages. When the router node receives an RREP message, it increases its *AnycastGate* counter by *one*. The corresponding data receiver is also inserted into *DataReceiver*. If the counter equals *one*, the route record is generated for the data receiver specified in the RREP message. The RREP message is then forwarded to the sensor node. Otherwise, the RREP message is discarded. The route record is then used for relaying DATA messages. The transmitted DATA messages are kept in the DATA buffer of the ZigBee module before receiving an ACK message. If the ACK message is not received in a timeout period, a new data receiver is selected for retransmission [11].

The operations of the router device are described as follows.When the router node receives an RREQ packet, it checks the RREQ message in the receiving buffer to determine whether it has received a new RREQ message. If *yes*, then the router node adds route record for the source node to its routing table.

It also broadcasts the RREQ message to its neighbouring nodes. When a router node receives an RREP packet, it stores the data receiver address into a *DataReceiver* list and augment its *AnycastGate* counter by *one*. If the counter is larger than *one*, then the router node discards this RREP packet directly. Otherwise, the router node adds a route record for the destination node to its routing table. With the *AnycastGate* counter, the subsequent RREP messages for the same destination node would be discarded since the first RREP message usually corresponds to the route of the nearest data receiver to fulfil the requirement of anycast routing. When a DATA message is received, its forward address is used to screen for the router node. If *no*, the router node relays the DATA message to downstream according to its routing table. The DATA message is also stored in the buffer of the ZigBee module for the requirement of reliability.

Otherwise, the DATA is received and the packet is discarded. This router will periodically monitor the ACK message. When the router device receives an ACK message, it removes the acknowledged DATA message from its buffer. If the ACK message is not received within a predefined timeout period or an RERR message is received, then the router device deletes the route record of the destination node from its routing table and *DataReceiver* list. The value of *AnycastGate* counter is decreased by *one*. If the value of *AnycastGate* is still larger than *zero*, there is at least one another data receiver in the *DataReceiver* list. The router node then retransmits the DATA message to the new data receiver. Otherwise, an RERR message is created and transmitted to the source node. We note that although the router node only forward the first RREP message to the sensor node, the sensor node might still receive more than one RREP message. Consider a WMN with daisy-chained router nodes and two data receivers located at both ends. For a sensor node located between two router nodes, its RREQ message is forwarded by both router nodes. Both data receivers will receive the RREQ message and reply with an RREP message. Consequently, the sensor node receives two RREP messages and stores the data receiver of the second RREP message in the *DataReceiver* list for improving reliability.

Data Receiver: The data receiver is responsible for receiving the DATA messages through a ZigBee module and extracts data to the computer through a USB interface, which emulates an RS-232 port. The interface also provides dc power to the data receiver.The operations of the data receiver are described as follows.When the data receiver receives an RREQ packet, it checks the RREQ message in the receiving buffer to determine whether this is a new RREQ message. If *yes*, then the data receiver adds route record for the sensor node in its routing table. Meanwhile, it sends an RREP message to the sensor node. It extracts vital signs from the received DATA message. The extracted vital signs are transmitted to the computer through the USB interface. The data receiver also uses a timer to trigger the transmission of ACK messages for the sensor node.

The proposed reliable transmission protocol is essentially a hybrid solution, which merges the routing algorithm with reliable data transmission. This hybrid approach offers the advantages of better efficiency. With the anycast routing, the sensor node can transmit vital signs to the nearest data receiver. Unlike the traditional end-to-end approach of reliable data transmission, our protocol can provide fast rerouting and retransmission. As a result, the latency of data transmission can be shortened while the data reliability can be maintained.

Fall Monitoring System: From the perspective view of patient monitoring, an accident detection system such as a fall monitoring system can provide good supervising assistance on patient care. However, it is crucial to avoid the vital signs missing, especially, a fall event because it may be mortal to the patients. Based on the reliable forwarding scheme for ZigBee wireless sensor networks, we propose a region-based location awareness fall detection system. This system includes three parts: fall detection scheme, region-based indoor position procedure and an ECG sensor. When a fall event is detected, a 4-s ECG data is also transmitted through the proposed protocol to achieve the purpose of reliable transmission. In the first part, we focus on home incidents of falls caused by accidents such as faint or weakness. The mobile device with a 5G triaxial accelerometer is placed on waist to measure triaxial accelerations with 200 Hz sampling. According to sensor's orientation, the *x*-axis is frontal direction, the *y*-axis is vertical side and the *z*-axis equals to sagittal side. The algorithm is shown in Fig. 3. First, it calculates *SVMa* (sum vector magnitude of accelerations) continuously. As soon as the value of *SVMa* is larger than 6 G, the fall detection scheme will give

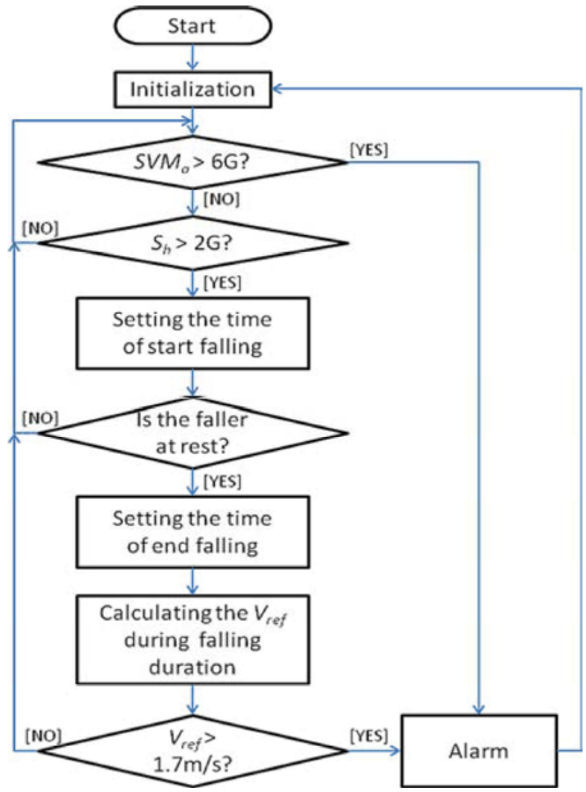

Fig. 3: Fall detection algorithm.

alarm directly because the values of *SVMa* on daily activities are all under 6 G. If the value of *Sh* (acceleration on the horizontal) is bigger than 2 G, that means the body tilts forward or backward acutely. Then it will use continuous 0.3 s stable *SVMa* within 2 s to estimate whether the faller is at rest or not. If the faller is at rest, it will integrate *V*ref (reference velocity) during the falling duration. Finally, the proposed fall detection scheme will give alarm when the value of *V*ref is over 1.7 m/s.As soon as a fall has happened, the system will start the region based indoor position procedure that includes four stages,

- The mobile device broadcast a message to the wireless routers which can be reached by signal strength indicator (RSSI) signal.
- These wireless routers feedback the RSSI values that they have received.
- The mobile device transmits the fall alarm to the wireless router that received the largest value before.
- This wireless router fills its own short MAC address in the router ID field of DATA message (see Fig. 2) to indicate that the fall event happened in this region. The DATA message is then sent to a data receiver.

After a fall event is detected, 4-s ECG data is also transmitted to the data receiver and shown on the GUI display. Monitoring the subject's heart rate and possible cardiac event, such as sinus tachycardia, sinus bradycardia, premature ventricular contraction (VPC) and short-run ventricular tachycardia (VT) is helpful in emergency response for heart attack of unintentional falls. Moreover, some diseases cause large change in heart rate like cardioinhinitory carotid sinus hypersensitivity would induce non accidental falls. Therefore, the 4-s ECG data can not only help the caregivers to know the urgency of the fall-induced injury, but also show the probable reasons of falls.

RESULTS AND DISCUSSION

We evaluate the performance of our scheme by using a network simulator. In the performance evaluation based on a network simulator, we demonstrate the scalability of our scheme with respect to the number of wireless nodes. Next, we show the prototype of our fall monitoring system to demonstrate the feasibility of our scheme. We also measure the end-to-end transmission delay through a cellular network and the power consumption of our wireless nodes.

We start from the simulator-based performance evaluation. The evaluation was conducted by using the IEEE 802.15.4 model in the INET framework of a publicly available network simulator, OMNet++. The size of the simulation area is 1000 × 600 m2. The performance metrics include control overhead, search latency and delivery ratio.

The control overhead shows the total number of the request and reply packets. From fig. 4, among these three schemes, the broadcast scheme consistently has the highest control overhead and our scheme has the least. When the number of data receivers increases to 10, our scheme generates 33% less control messages than that of the broadcast and multicast schemes. Since anycast routing only communicates with the closest data receiver, our scheme has the least control overhead as well as energy consumption.

The search latency is the time period from sending the RREQ message until receiving the first RREP message. From fig.5, both schemes have significantly higher search latency than our scheme since their source node must wait for reply messages from all data receivers. Our scheme, by contrast, shortens the search latency by only finding the closest data receiver.

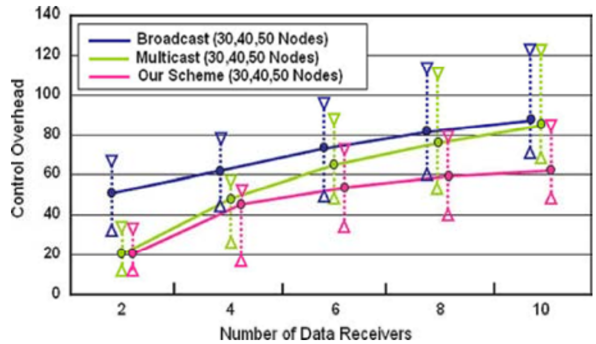

Fig. 4: Control overhead.

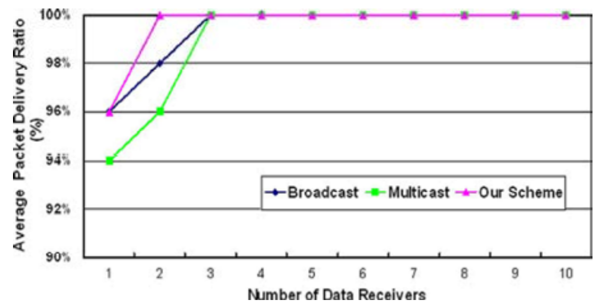

Fig. 5: Average search latency.

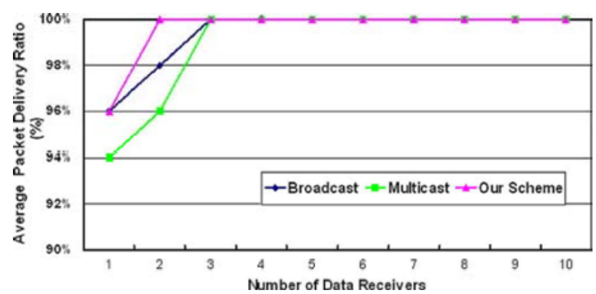

Fig. 6: Average packet delivery ratio.

The delivery ratio indicates the percentage of the successfully transmitted DATA messages. When there is only one data receiver, our scheme has the same performance as the broadcast scheme. However, delivery ratio of our scheme achieves 100% with two data receivers. By using fast rerouting, our scheme can effectively reroute DATA messages to a new data receiver when a link/node failure occurs. Both broadcast and multicast schemes require three data receivers to assure data reliability. By jointly considering the control overhead, our scheme has the best feasibility than the other schemes.

From these simulations, we can infer that our scheme is more reliable and efficient when compared to both multicast and broadcast.

CONCLUSION

This paper presents a reliable anycast routing protocol for ZigBee-based wireless patient monitoring. In the new scheme, mobile sensor node selects the closest data sink as the destination in a WMN. Therefore, the latency of route query and the number of control messages can be reduced simultaneously. The new protocol also has the capability of fast rerouting. Therefore, a broken path can be recovered in a short latency and the reliability of the transmitted vital signs can be assured. We implement a ZigBee-based prototype of fall monitoring system based on the new routing protocol. In the system, we integrate a triaxial accelerometer and an ECG sensor to achieve real-time fall detection and physiologic monitoring. When a fall event is detected, the closest router node to the sensor node is calculated. In addition, 4-s ECG signals are transmitted to the healthcare professional for notifying the patient status. The system can be combined with the next generation WWAN, such as LTE or WiMAX, to achieve pervasive healthcare. Through the integration with WiMAX, we demonstrate that our scheme can improve the feasibility of wireless patient monitoring systems.

REFERENCES

1. Chen, *et al.,* Jan, 2012. A reliable transmission protocol for zigbee-based wireless patient monitoring.
2. Chen, S.K. and P.C. Wang, 2010. An anycast-based emergency service for healthcare wireless sensor networks, IEICE Trans., 93-B(4): 858-861.
3. Wang, J. and X. Lu, 2003. Route recovery based on anycast policy in mobile ad hoc networks, in Proc. Int. Conf. Commun. Technol., 2: 1262-1265.
4. Huang, C.N., G.C. Chen, C.Y. Chiang, J.S. Chang, S.J. Hsu, W.C. Chu and C.T. Chan, Fall detection system for healthcare quality improvement in residential care facilities, J. Med. Biol. Eng., 30(4).
5. Choi, J.S. and M. Zhou, 2010. Performance analysis of Zigbee-based body sensor networks, in Proc. IEEE Conf. Syst., Man Cybern, pp: 2427-2433.
6. OMNeT++ Community Site. [Online]. Available: http://www.omnetpp. org/ (Accessed 2010).
7. Tatyana Aleksandrovna Skalozubova and Valentina Olegovna Reshetova, 2013. Leaves of Common Nettle (Urtica dioica L.) As a Source of Ascorbic Acid (Vitamin C),World Applied Sciences Journal, 28(2): 250-253.
8. Rassoulinejad-Mousavi, S.M., M. Jamil and M. Layeghi, 2013. Experimental Study of a Combined Three Bucket H-Rotor with Savonius Wind Turbine, World Applied Sciences Journal, 28(2): 205-211.
9. Vladimir, G. Andronov, 2013. Approximation of Physical Models of Space Scanner Systems World Applied Sciences Journal, 28(4): 528-531.
10. Naseer Ahmed, 2013. Ultrasonically Assisted Turning: Effects on Surface Roughness World Applied Sciences Journal, 27(2): 201-206.
11. Tatyana Nikolayevna Vitsenets, 2014. Concept and Forming Factors of Migration Processes Middle-East Journal of Scientific Research, 19(5): 620-624.