Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 14 (24): 3479-3485, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.3479.3485

Efficient Routing Techniques for Wireless Sensor Networks

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Abstract: In Wireless Sensor Networks (WSNs), sensor nodes perform sensing, processing and relaying operations that consume the energy of a sensor node. WSN routing protocols are concerned with forwarding data from the source to destination with less energy consumption to extend the network lifetime. Among the different WSNs routing protocols, the advantages of network structure classes (flat-based, hierarchical-based and location-based) routing protocols are considered here to introduce routing protocols that are suitable for different environments. Two clustering based routing protocols; Fixed-environment Location-based Clustering Routing Protocol (FLCRP) and a Mixed-environment Location-based Clustering Routing Protocol (MLCRP) are introduced in this study. The performance of the proposed protocols is evaluated and compared with Low Energy Adaptive Clustering Hierarchy (LEACH) and Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) protocols using NS2-Software with different scenarios. The results have shown that the proposed systems are better than LEACH and LEACH-C for small networks in terms of throughput, packet delivery ratio, delay, energy consumption. On the other hand and for large networks, LEACH and LEACH-C are better in terms of jitter and energy consumption.

Key words: Sensor networks, clustering, routing, mobile nodes, energy efficiency

INTRODUCTION

An important subclass of *ad-hoc* networks is the Wireless Sensor Network (WSN) which has the capability of interaction with the environment (Matin, 2012). Wireless Sensor Network consists of many sensor nodes which are tiny devices that include three basic components: A sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage and a wireless communication subsystem for data transmission (Eksim, 2012). The basic goals of WSNs are measurements, detection, classifications and tracking of physical variables. These goals require a large amount of battery-powered wireless sensors and are usually designed for long-term deployments with no human intervention. Subsequently, energy efficiency is one of the main design objectives for these sensor networks (Matin, 2012; Biradar *et al*., 2009). In this study, we propose two clustering protocols aiming to obtain better performance including less energy consumption for fixed and mobile nodes.

Low Energy Adaptive Clustering Hierarchy (LEACH) is the first proposed energy efficient clustering routing protocol (Heinzelman *et al*., 2000). In LEACH protocol, there are two phases; setup phase and steady state phase. In setup phase, the clusters are formed by selecting the Cluster Head (CH) randomly. In steady state phase, the cluster heads aggregate the received data and forward the data to the Base Station (BS) directly with single hop. Cluster Heads (CHs) are changed along the time in order to balance the energy dissipation of nodes to increase the network lifetime. Manjeshwar and Agrawal (2001) proposed a Threshold sensitive Energy Efficient sensor Network (TEEN) in which two types of thresholds (hard and soft thresholds) are used for the energy reduction. Sensor nodes sense the environment continuously but the transmission is done less frequently to conserve more energy.

The adaptive version of TEEN; Adaptive Periodic Threshold sensitive Energy Efficient sensor Network (APTEEN) (Manjeshwar and Agrawal, 2002) is an extension of TEEN and it is a hybrid protocol that can operate as a proactive protocol like LEACH and reactive protocol like TEEN. Heinzelman *et al*. (2002) proposed a Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) which is similar to LEACH in operation except in cluster formation process. In LEACH-C, the BS is responsible for selecting the CHs and their members by collecting information about the current locations of nodes and remaining energy levels during the setup phase to produce better clusters that require less energy for data transmission. Hybrid Energy-Efficient Distributed (HEED) (Younis and Fahmy, 2004) is a multi-hop

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inter-cluster communication protocol with explicit consideration of energy. In HEED, the selection of CHs depends on two parameters; residual energy of the node and the intra-cluster communication cost. This aims to distribute CHs evenly through the network.

Besides the aforementioned protocols, there are several other protocols (Ding *et al*., 2005; Zytoune and Aboutajdine, 2014), which differ in their techniques in a way or another, but still use the same principles as the above mentioned protocols. The proposed methods here are based on using the location, energy and distance information in clustering and routing process.

MATERIALS AND METHODS

Proposed routing protocols: WSN routing protocols can be classified using different ways but the most common way of classification is based on network structure. This classification is divided into three classes: Flat-based routing protocol with the advantage of route optimality, Hierarchical-based routing protocols (e.g., LEACH, TEEN, APTEEN and HEED (Heinzelman *et al*., 2000; Manjeshwar and Agrawal, 2001, 2002; Younis and Fahmy, 2004) with the advantage of better energy efficiency (Rathi *et al*., 2012) and Location-based (geographic) routing protocols (e.g., LEACH-C, GAF (Heinzelman *et al*., 2002; Xu *et al*., 2001) with the advantage of dealing with location information for each node. The proposed protocols here combine the advantages of the three main classes (flat, hierarchical and location) based routing protocols. They are clustering routing algorithms based on energy, location and distance information in the cluster formation process and route construction process.

FLCRP operation: FLCRP is designed to operate in an environment of fixed sensor nodes only. It is an event-driven and clustering protocol depends on node energy, location and distances separating nodes and BS. It is a single-hop intra-cluster and multi-hop inter-cluster communications. The operation of FLCRP can be divided into; setup-phase and steady state-phase (data sending).

Setup phase: Setup-phase in FLCRP covers; area preparation, cluster head selection, cluster formation and route construction.

Area preparation: The coverage area of the network is assumed to be square with total area of A^2 and is divided into sixteen square regions. It is assumed that each node can find its location by using information derived from GPS and hence the boundaries of its region will be known.

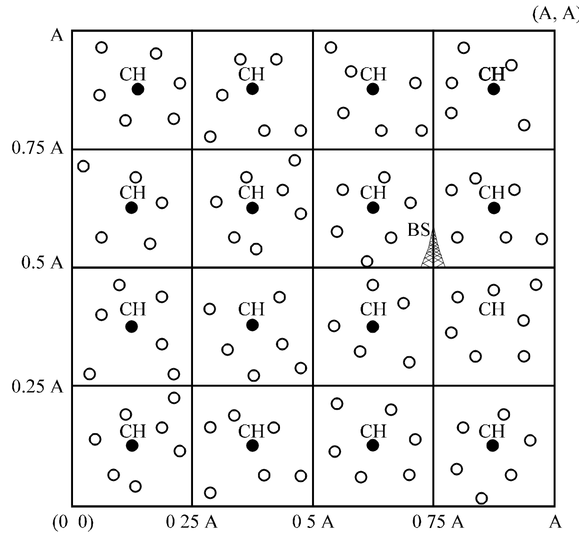

Fig. 1: Initial CHs and nodes distribution

Each node will determine its location using a series of location comparisons relative to predetermined thresholds. These thresholds are located midways in the x and y directions of each square starting from the big square with area of A^2, until the smallest square with an area of $A^2/16$. The final 16 square regions are shown in Fig. 1. The benefit of letting each node to know the region where it resides is to assist in clustering and routing.

CH selection: After defining the boundaries of each square, the next step is to select the Cluster Heads (CHs). CHs selection occurs in the setup-phase at the beginning of each round either in centralized manner by central node (like BS) or in distributed manner (via negotiation or using tentative CHs). This can be performed by BS or letting nodes to nominate the suitable nodes to be CHs. This will consume an extra energy. In FLCRP, CHs selection does not depend on (negotiation, tentative CHs or BS) but instead, it is assumed that the CHs of the first round are located at the center of each square as shown in Fig. 1. When a new round begins, CHs of the previous round collect information (energy and distance) from their members in the same cluster and find the nearest member to the center with a large amount of energy to become CH for the next round. This will take place whenever the energy of the current CH becomes less than a predetermined threshold. The latter is defined according to the following empirical Eq. 1:

$$\text{En\_Th} = \left(1 - \left[\frac{r}{R} \times \text{Rand }(0, 0.3)\right]\right) \times \text{Re\_En} \qquad (1)$$

where, En_Th is the energy threshold of each CH, r is the order of current round, R is the total number of rounds and Re_En is the remaining energy of each node. The above equation and its parameters are found following extensive simulation tests. The intention was to avoid selecting the node as CH when the energy is not totally consumed. The remaining energy is reduced by specific amount following any transmission. This depends on the range of transmission between given node and the destination node (CH or BS). The present CH could be the CH of the next round again if its energy is greater than the above threshold; otherwise it will select a new CH.

Cluster formation: After CH selection process, the clusters are formed. Each CH announces itself by broadcasting advertisement packet that includes the location information of the CH. Normal nodes of the same region will receive this packet then calculate the distance between CH and themselves according to Eq. 2:

$$D=\sqrt{(Xm-Xch)^2+(Ym-Ych)^2} \quad (2)$$

where, Xm and Ym are the coordinates of given member node and Xch and Ych are the coordinates of the CHs nodes. The nodes then send join request packet which includes their energy level and location information together with the distance to the CH. CH will receive the join request packet and register the nodes as its own members.

Routes construction: BS periodically broadcasts a beacon packet which includes the BS location. All nodes will receive this beacon packet; if the node is a normal node, it will calculate the distance to BS and compare it with the distance to its CH that is found previously. If the distance to BS is smaller than the distance to CH, then the node will join the BS directly and builds the route toward BS rather than CH as shown in Fig. 2 (blue line). If CH node received BS beacon, it will broadcast the beacon with information regarding its location and distance from BS. When another CH receive the beacon packet calculate the distance to given CH. Thus, each CH finds the total distance to the BS. The CH then broadcasts such information to all nodes. The total distance from any CH to BS is calculated using Eq. 3:

$$T\_d_{CHr\_BS} = d_{CHs\_BS} + d_{CHs\_CHr} \quad (3)$$

where, $T\_d_{CHr\_BS}$ is the total distance between the current CH and the BS, d_{CHs_BS} is the total distance between the previous CH and the BS and d_{CHs_CHr} is the distance between the current CH and the previous CH. When this total distance is greater than d_{CHs_BS}, the newly selected CH will communicate directly with BS. To select the best route, the current CHs will make a comparison among the total distances of the previous CHs to BS and then select the CH that has the shortest distance to BS as the next hop. Finally, the best route to be selected is the one with the shortest distance to BS as shown in Fig. 2. This routing is similar to Directed Diffusion, in which there are different routes to BS but the best route is selected (Intanagonwiwat *et al*., 2000).

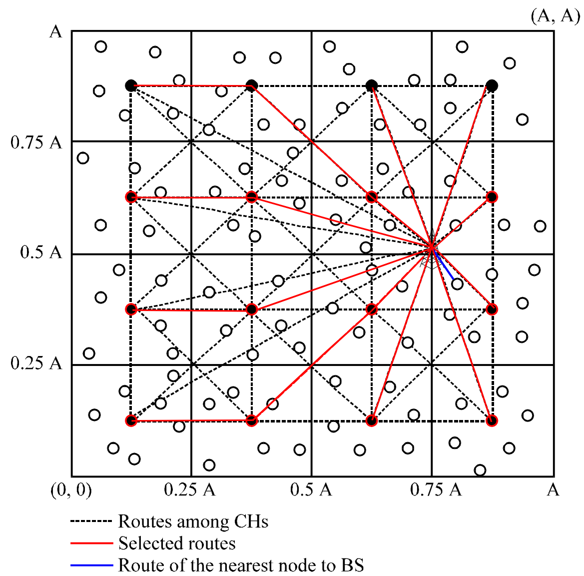

Fig. 2: WSN with different routes and best route selection step

Steady state phase: After completing the setup phase, the steady state phase begins whereas each node sends its data packets to the BS (the destination) according to the routing table. If the source node is normal node, it will send its data packets either directly to BS, when it is closer to BS than CH, or indirectly via its CH. If the node is CH, it will send its own data packets and the collected ones from its members to the next CH as a next hop until its final destination (BS).

MLCRP operation: MLCRP is a modification of FLCRP, where it can be used in fixed and/or mobile environment. Here each node checks periodically its location relative to cluster boundaries. If the node moves out of its cluster, it must send incoming-packet to the CH of the new cluster. The CH of the new cluster will register the incoming-node. If the incoming-node is a CH of another cluster, it must send an advertisement non-CH-packet to its member nodes.

Then, the latters will send a packet containing energy and location information. The leaving CH will select the best new CH for that cluster according to previous stored information. Comparing MLCRP to FLCRP shows that the former provides support for mobility and it does not send any join request packet after receiving the advertisement packet from the CHs at the setup phase. Instead, it sends a packet to specify its distance and energy to the current CH when the current CH wants to nominate a new CH.

Features of the proposed protocols: The main features of FLCRP and MLCRP proposed protocols are:

- Both are single-hop/intra-cluster and multi-hop/inter-cluster based connectivity protocols
- The CH selection depends on the location, the distance and the remaining energy of the node
- They are distributed clustering algorithms
- MLCRP supports mobility (i.e., CHs may be mobile or fixed)
- In the proposed protocols (unlike previous protocols), nodes closed to the center of the region consume less energy
- Routing scheme selects best path in CHs level, thus, it is more route optimal than other clustering protocols
- Keeping a routing table assists in finding the nearest CH as a next hop, thus consuming less energy
- If the distance between normal nodes and BS is less than that to its CH, it will communicate directly with BS

RESULTS AND DISCUSSION

The performance of the proposed protocols together with LEACH and LEACH-C are performed using NS-2 software. In the simulation, it is assumed that the total area is (100×100) m^2. The simulation time is 1000 sec with a round duration is 20 sec. Clearly, any area could be used instead. Different numbers of nodes are considered mainly 20, 60 and 100. These are distributed randomly throughout the whole area. The packet size is assumed to be 500 bytes per packet. The BS is fixed and located at (75, 50 m) as shown in Fig. 1. The type of traffic is assumed to be constant bit rate of 1 Mb sec^{-1}. The used wireless channel model is the two ray ground propagation model. The initial energy in each node is taken to be 3 while for BS, it is 1000 J (these values are similar to those used by the reference systems LEACH and LEACH-C (Heinzelman *et al*., 2000, 2002). Two versions of the proposed protocol MLCRP are considered. MLCRP-F is MLCRP with fixed nodes only,

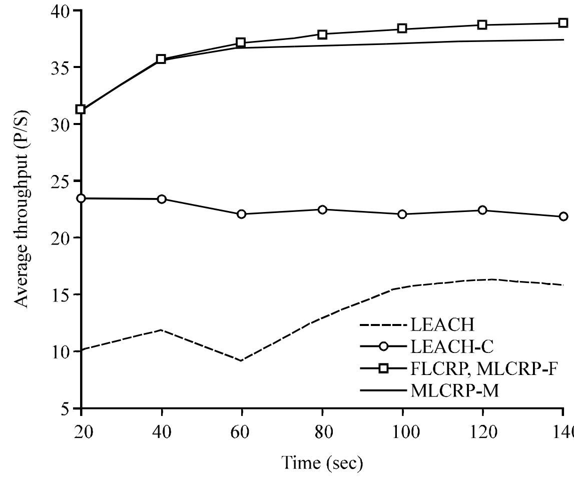

Fig. 3: Average throughput for 20 nodes scenario

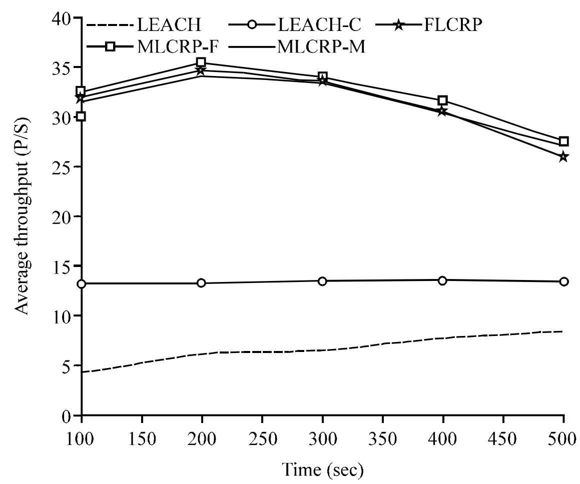

Fig. 4: Average throughput for 100 nodes scenario

while MLCRP-M with 50% of the total number of nodes is with speed being selected randomly in uniform manner from 0-10 m sec^{-1}. The results of proposed protocols, LEACH and LEACH-C are obtained and evaluated in terms of the following performance parameters; the average throughput, the packet delivery ratio, the average end to end delay, the average jitter and the average energy consumption.

Average throughput: Throughput is the measure of the successfully received data packets per unit time. Figure 3 and 4 show the throughput performances for 20 and 100 nodes, respectively. Both figures show that the proposed protocols perform better than LEACH and LEACH-C protocols. This is due to a relatively small overhead used in the proposed protocols. Figure 4 shows

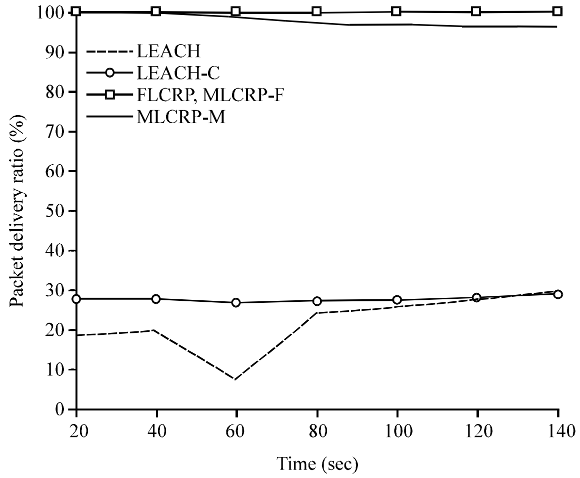

Fig. 5: Packet delivery ratio for 20 nodes scenario

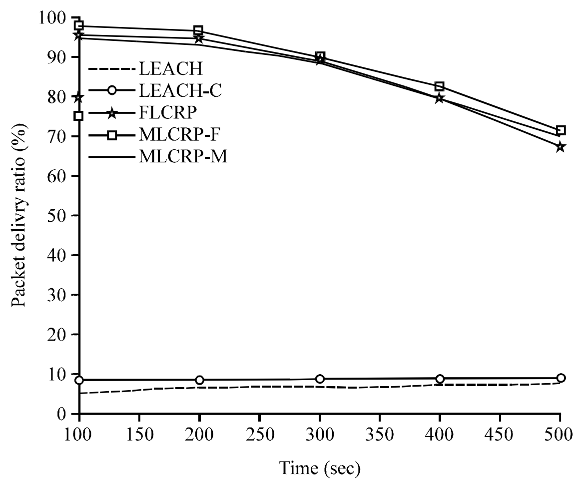

Fig. 6: Packet delivery ratio for 100 nodes scenario

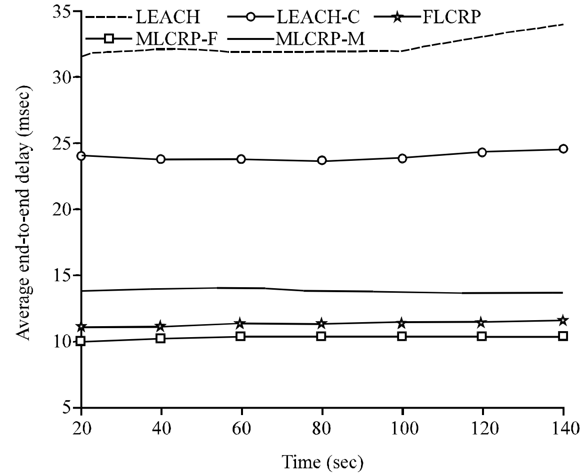

Fig. 7: Average end to end delay for 20 nodes scenario

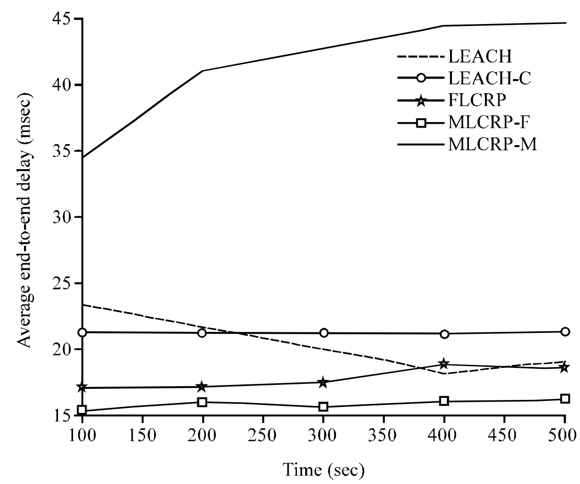

Fig. 8: Average end to end delay for 100 nodes scenario

(for 100 nodes case) that the average throughputs of the proposed systems are decayed as the operation time increased beyond 500 sec because of the increase in the traffic which consumes the energy of the nodes that are closer to BS. These nodes will die first and cause dropping of many packets. The average throughput of FLCRP is slightly less than of MLCRP-F, which cannot be recognized in Fig. 3.

Packet delivery ratio: Packet delivery ratio is the percentage of the successfully delivered packets. Figure 5 and 6 show that the packet delivery ratios of FLCRP, MLCRP-F and MLCRP-M are better than those of LEACH, LEACH-C. Figure 6 shows (for 100 nodes case) the packet delivery ratio of FLCRP and MLCRP-F is better than that of MLCRP-M for the time below 500 approximately. For longer time of operation, the packet delivery ratio of MLCRP-M begins to be better than that of FLCRP, since with mobility the traffic load is uniformly distributed among the nodes.

Average end to end delay: Delay or latency is the average time required by the packets to travel from the source to the destination. Figure 7 shows the average end to end delay of FLCRP, MLCRP-F and MLCRP-M being better than that of LEACH, LEACH-C. This is due to the additional overhead needed in cluster formation of LEACH and LEACH-C. Figure 8 shows that the average end to end delay of MLCRP-M is higher than that of all other protocols since the

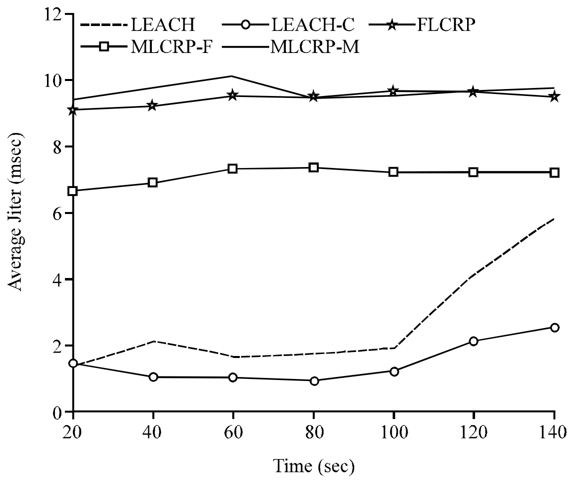

Fig. 9: Average Jitter for 20 nodes scenario

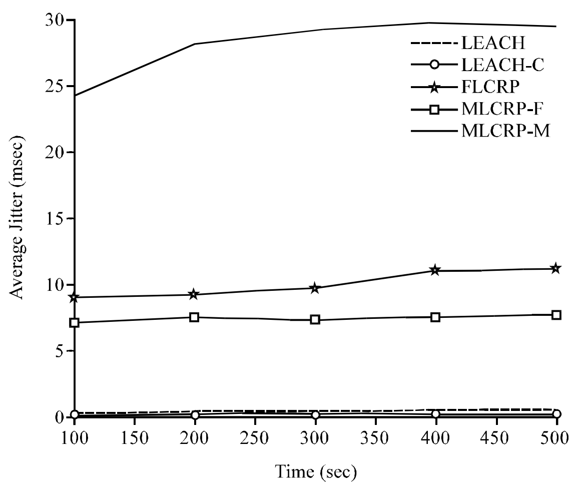

Fig. 10: Average Jitter for 100 nodes scenario

mobility will increase the time of sending and receiving the packets due the possible routes changing.

Average jitter: The average jitter is the average in delay variations introduced by the network. Figure 9 and 10 show that the average jitter of LEACH and LEACH-C are better than those of FLCRP, MLCRP-F and MLCRP-M. This is due to the fact that LEACH and LEACH-C are TDMA based system.

Average energy consumption: Energy consumption occurs in packet transmission, packet reception and processing by each node during network operation. Here, the average energy consumption is taken as the average amount transmission and reception energies of all nodes.

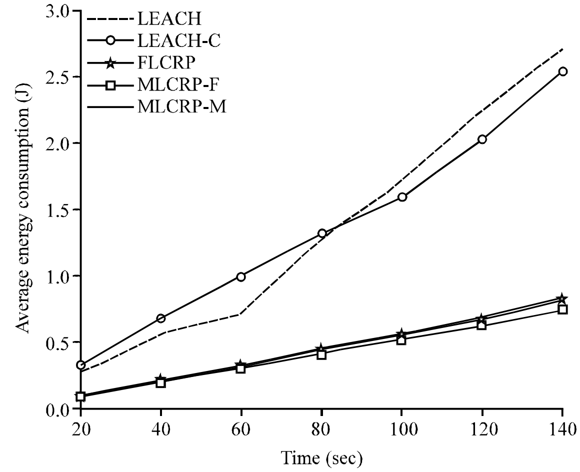

Fig. 11: Average energy consumption for 20 nodes scenario

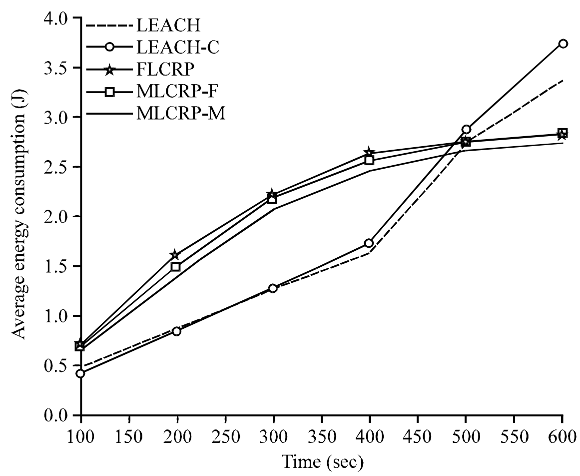

Fig. 12: Average energy consumption for 100 nodes scenario

Figure 11 shows that the average energy consumption of the proposed protocols (FLCRP, MLCRP-F and MLCRP-M) is less than those of LEACH and LEACH-C. Figure 12 shows (in case of 100 nodes) that LEACH and LEACH-C consume less energy than the proposed systems. For the case of 20 nodes (Fig. 11), relatively lower energy occurred in the case of the proposed protocols, while for 100 nodes, the consumed energy increased with time. This is due to the fact that more nodes and hence more transmissions are involved in the process of CH selection where different control packets are broadcasted as compared to reference protocols (LEACH and LEACH-C). This means that the energy consumption in the proposed protocols is increased with the increasing of data traffic along the time in large networks.

CONCLUSION

Two wireless sensor network routing protocols based on clustering are proposed in this study. These protocols, called FLCRP and MLCRP, are suitable for both fixed and or/and mobile environments. The proposed protocols make use of the useful features of flat-based, cluster-based and location-based routing protocols. It is shown that, dividing the whole WSN area into small clusters reduce the distance between sensor nodes and their CH and also reduce the distance among CHs. The simulation tests have shown that the two proposed protocols performed better than the reference protocols (LEACH and LEACH-C). This is true when most usual performance measures are considered. These covered measures are the average throughput, the packet delivery ratio, the average end to end delay, the average jitter and the average energy consumption. The proposed protocol MLCRP seems to be very promising protocol for the case of large network with mobility. Here, a sort of balance is obtained among all neighboring nodes, which is reflected in improvements in throughput, packet delivery ratio and average energy consumption as compared to non-mobile case.

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