Extending Network Lifetime in Wireless Body Area Nanonetworks: A Design of a Cluster-Based Routing Protocol

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Abstract: A Wireless Nanosensor Networks (WNSNs) consists basically of a group of nanonodes that communicate with each other through a wireless transmission in an adhoc manner. The recent developments in nanotechnology and wireless communication, to be used in various applications, foster the development of Wireless Body Area Nanonetworks (WBANNs). They are gaining traction as crucial networks for reducing the demand for patients and assisting the elderly and chronically sick in living independently. One of the fundamental issues in wireless nanosensor networks (WNSN) is to fulfill the nanonodes' energy constraints while maintaining system reliability. Clustering technique has been demonstrated to be a well-organized approach to provide energy-efficient communication for WNSNs. A cluster-based routing system for wireless body area nanonetworks is presented in this study, which allows data to be transferred through the network with minimal energy consumption and a longer network lifespan through multi-hop communication. When compared with the benchmarked protocol, simulation results demonstrate that the proposed protocols extend network lifetime and reduce energy usage with an average performance improvement of 28.49% in terms of network lifetime.

Keywords: Wireless Nano Sensor Networks, Wireless Body Area Nanonetworks Energy Harvesting, Routing, Network lifetime

Introduction

Due to the abundance of cutting-edge applications offered by the introduction of Nanotechnology, the Wireless Nanosensor Network (WNSN) has recently received a lot of attention. WNSNs have a wide range of applications and may be used in a variety of fields including environmental monitoring, industrial, biomedical, and military applications, among others. Sensing, data processing, and communication at the nanoscale are the key duties of a nanosensor node in a WNSN. Because of their small size, energy storage, and processing capabilities, individual nanonodes can only execute a few simple operations which are restricted to their immediate surroundings (Akyildis and Jornet, 2010).

At the cellular level, implanted nanoscale devices exhibit exceptional properties for non-invasive illness detection, diagnosis, and therapy (Pierobon *et al.*, 2013).

These nano-nodes are expected to enhance nanomedicine applications such as early cancer cell identification, identifying kidney damage, mending damaged cells, and delivering medications, heat, or light to particular cancer cells (Eckert *et al.*, 2013). The communication of the implanted nanonodes is enabled by the ability of novel nanoantenna based component to transmit and receive electromagnetic radiation with high bit rates in the terahertz frequency band which is different from the traditional wireless carrier-based communication model.

The overall network performance of the nano-nodes communicating at terahertz band frequency will be affected significantly by path loss due to high molecular absorption and low transmission power (Pierobon *et al.*, 2013). Based on this reason, it is essential to develop a routing protocol that will guarantee a multihop communication in wireless nanosensor network.

In order to deal with the little amount and flexibility of energy storage using nano batteries, the nanosensors require an efficient energy harvesting system. WNSNs requires a new communication protocol based on multihop as a result of high node density in the network in combination with the need to efficiently operate perpetually and high propagation loss in the terahertz channel as such: Pierobon *et al.*, (2013) propose a routing framework for WNSN with the aim of ensuring lifetime operation and increasing network performance by maximizing the use of energy harvested. Nevertheless, this routing protocol exhibits a high computational complexity. Liakos *et al.*, (2016) put forward a routing system that can be deployed dynamically in a nanonetwork for software defined application. Stationary, compact topologies are studied with many undistinguishable nodes. But their protocol is not suitable for intrabody health monitoring application. A new energy-efficient multihop routing protocol was proposed by Xu *et al.*, (2016) based on the network condition. Nevertheless, the EEMR protocol cannot solve the problems of energy exhaustion of the nano-nodes which result into network failure. Yu *et al.*, (2017) propose a low-complexity Forwarding scheme for the backhaul tier in nanonetworks. The protocol is intended for a situation in which nanonetworks are using multi-hop polling to introduce data acquisition. Nevertheless, it fails to consider nano-nodes energy consumption which is a vital feature of nanonetworks. Xu *et al.*, (2018) proposed a multipath routing protocol for wireless multimedia nanosensor network that selected a next hop node based on game model. However, the protocol is not suitable for intrabody wireless nanosensor network (iWNSN). Piro *et al.*, (2014) proposed a hierarchical network architecture, which harmonizes a BANNET and a macro-scale health care monitoring system as well as two separate energy-harvesting protocols. However, the computational complexity of the optimal scheme is high. Lee *et al.*, (2015) proposed a wireless nanosensor network model based on On-Off Keying (OOK) protocol and TDMA framework for intrabody disease detection. But they did not consider the energy harvesting process of the nanosensor node. Liu *et al.*, (2017) proposed an efficient scheme for data collection in a Body Area Nanonetwork. However, if a nano-node is not within the coverage of any nano-router, it waits until the signal can be received by one of them which results to delay. Afsana *et al.*, (2018) proposed an energy-conserving routing scheme suitable for wireless body Nanosensor network communicating over the terahertz band. However, a reasonable mechanism for updating the cluster head was not provided. Also, consideration is not given to failure of cluster head. Xu *et al.*, (2019) proposed an energy balance clustering routing protocol for intrabody nanosensor node. In the EBCR protocol, a hierarchical clustering method was adopted in order to reduce communication load on nano-nodes. However, consideration is not given to failure of cluster head which might leads to data packet loss. Fahim *et al.,* (2020) proposed a routing protocol that integrates the attributes of Exponential Weighted Moving Average Based Opportunistic Data Transmission and Artificial Colony Algorithm Based Query Response Transmission to efficiently handle the routing challenges in body nanosensor networks. However, if a nano-node is outside of a nano- router's coverage area, it waits for the signal to arrive, resulting in a delay. Though, because innovative ways for enabling energy-efficient communication in WBANNS are still in the early phases of research, additional work is necessary.

Owning to the fact that energy required for data transmission is always more than that necessary for processing (Sadiq *et al.,* 2016), clustering nanonodes is beneficial (Salami *et al.,* 2019). A subset of nodes becomes nano-cluster head (NCH) nodes in WNSN clustering techniques, which receive data from a group of nanonodes and process and transmit it to the base station (BS), or to another NCH in the case of a multi-level network. Although clustering can lower energy consumption, the biggest issue is that it concentrates energy usage on the NCHs (Zakariyya *et al.,* 2020). NCH nodes use more energy than non-NCH nodes because they must do additional operations before transferring data, such as data aggregation, compression, and encryption. Furthermore, because of the multi-hop routing aspect of a nano-sensor network, nano-nodes along routing pathways tend to have a larger burden and, as a result, drain their energy quicker than other nano-nodes. As a result, a cluster-based wireless nanosensor network protocol must be carefully developed in order to reduce data packet loss.

This work proposed the use of wireless energy transfer for those nano-cluster head (NCH) along the data forwarding path to the nanocontroller (NC) to minimize the data packet loss in the existing nanosensor network clustering protocol. The energy transfer process uses an algorithm that is mentioned in sequel. The rest of the paper continues with the following structure. Section 2 describes the network formation model and the clustering method. Section 3 gives the idea of wireless energy transfer and explains its methodology. Section 4 gives the performance analysis of the results. Finally, Section 5 concludes the paper.

Network Formation and Clustering

In this work, the network is modelled by assuming a network of energy constrained nano-nodes is implanted in the human body to form WBANN. The network is organized into layers so that naonodes may choose which layer they want to be affiliated with. With regard to the nanocontroller in the center, this network assumes a circular sensing field that is partitioned into many layers of concentric circles.

The radius of each layer is estimated as $nr_{xx}/2$ where *n* is the number of layers and r_{xx} is the transmission range of each nanosensor. The layers are split in such a way that the transmission range of each nanosensor in each layer encompasses the layers above and below it. All nanosensors compute their distances from NC after receiving a broadcasted message from NC, compare their distances to the layer radius, and register themselves to relevant layers.

The division of WBANNs into layers is achieved based on the number of nanonodes at each layer as follows.

$$\boldsymbol{n_k = 2^{k-1} \times \frac{N}{2^{a-1}}} \qquad (1)$$

where, n_k is the number of nano-nodes in the k^{th} layer, N is the total number of nodes in the network and a is the maximum number of layers.

The preliminary NCHs are chosen automatically once all nanonodes have been assigned to their layers and their residual energy has been calculated. All NCH applicants vying for the NCH post multicast their weight, marked by w_k to nearby candidates as part of the selection process.

$$\boldsymbol{w_k = \frac{E_{rk}}{E_m}} \qquad (2)$$

where, E_{rk} is the residual energy of nanosensor k, and E_m is the maximum energy. If a nanonode cannot discover another nanonode with a higher w_k, it proclaims itself NCH. Cluster creation occurs once NCHs have been chosen. The new NCHs broadcast short-range advertising messages to all nonclustered nanonodes in a layer. Non-member nanonodes with a higher received signal strength indicator (RSSI) issue a join request to their respective NCH and register as NCMs. This process is repeated until clusters have formed and all nodes have been allocated to their NCHs.

Proposed Technique

The residual energy of each NCHs node depends on different functions including data reception from member nodes, data aggregation and data forwarding. These functionalities results in different energy consumption rate at different NCHs nodes. After some time, it is expected that a NCH will deplete its energy during cluster operation due to data processing and forwarding activities as justified in past works of literature. Therefore, to compensate for the energy spent by the inner layer nano-cluster head in data aggregation and forwarding activities, an energy transferor node is assigned by a nano-controller to transfer an energy unit to the inner layer nano-cluster head.

The WET process is in two phases; in the first phase which occurs during the timeslot scheduling phase, the nano-controller estimate the residual energy of the cluster head and the amount of energy required to perform the cluster operation. Based on this, a time slot is assigned for the energy transferor nano-node for the WET process to the inner layer nanocluster head. It will be good to recall that the developed layering formula in equation (1) aids in distributing the deployed nano-nodes in each layer. Out of 100 nano-nodes deployed in the network, 98 are distributed in the network based on the developed layering formula. The remaining two nodes are assumed to be allocated to the two clusters in the first layer to serve as the energy transferor source.

The second phase is the WET session. During the WET session, the energy transferor node transfers energy to the NCH in its associated cluster. It is worth noting that this research assumed the energy transferor node is only responsible for the transfer of energy to the NCHS of its associated cluster and not involved in data gathering or data transmission role. Also, the choice of limiting the energy transfer scenario to the first layer is due to their closeness to the nano-controller. For that reason, it is assumed that the energy transferor node is in the range of the ultrasound power source that powers the nano controller.

In the flowchart presented in Fig. 1, 2 and 3, the notations n is the number of deployed nano-nodes, $d^i{}_{n,NC}$ denotes the i^{th}nano-nodes distance from the nano-controller, L_i represents the i^{th} layer number to which nano-node is assigned, a stands for the maximum number of layers, r_{xx} corresponds to the transmission range of each nano-node, E_{direct} is the energy require for direct transmission,

E_mul is energy require for multihop transmission, ETN represents the Energy transferor node, i denotes the layer IDs and j represents the cluster IDs

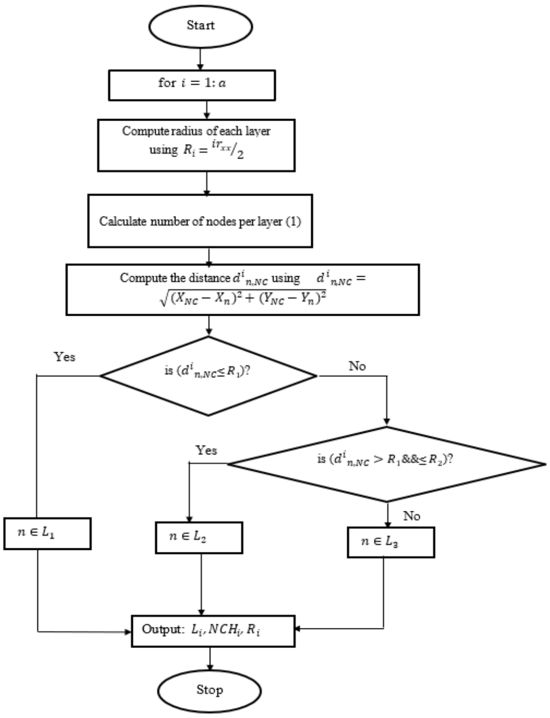

Fig. 1: Network formation and Layering Flowchart

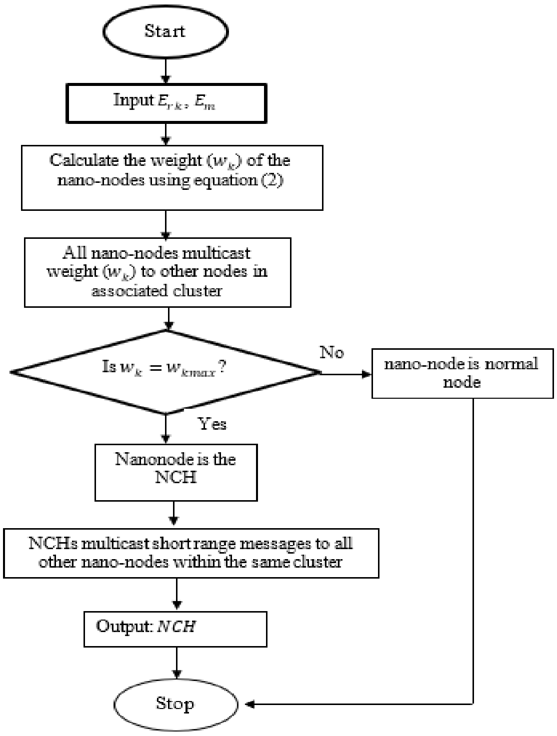

Fig. 2: Nano-Cluster Head Selection Flowchart

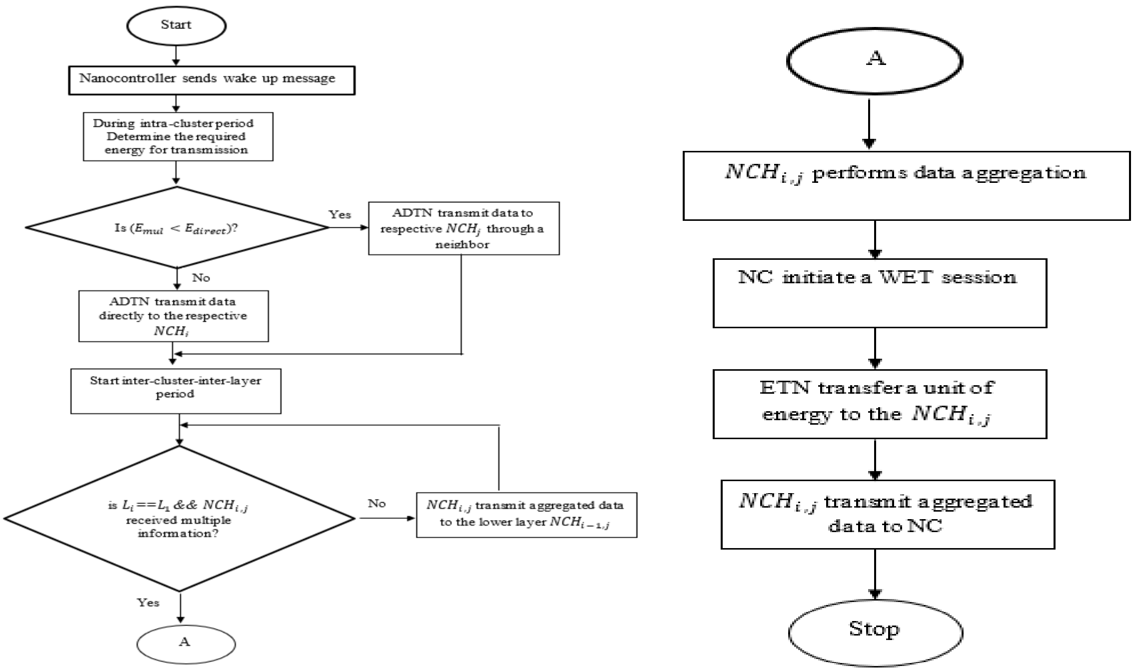

Fig. 3: Data Transmission Flow Chart for WET framework

Simulation Result

The simulation scenario in this work is based on the assumption that 100 nanonodes are deployed in human hand to construct a body area nanonetwork. All the nano-nodes have the same initial energy. The nanonode maximum energy is fixed as 4 µJ with data packet size of 128 byte and energy threshold value of 0.14 pJ. The total radius of simulation is 6 mm with maximum number of 3 layers. Results are extracted using MATLAB as a simulation tool to characterize the network models.

Network Lifetime

The comparison of network lifetime between the benchmarked and the proposed protocol is shown in Figure 4. The lifetime is evaluated based on First Node Dead (FND), Half Node Dead (HND) and Eighty Percent Node Dead (EPND). The FND refers to the times it took the first node to die in the network. HND refers to the time it takes to record 50% dead nodes in the network while EPND simply denoted the times it took 80% of the node to die in the network. Figure 4. reveals that the EBCR protocol registers FND during the 1010th round, but the proposed requires 1135th period to record the first dead node. Furthermore, the HND in the EBCR occurs in the 1450th round, but the HND in the proposed protocol occurs in the 1876th round. Finally, the EBCR records EPND at 1621th round as against the proposed protocol with its EPND at 2330th round. In terms of average percentage improvement, the proposed technique surpasses the EBCR protocol by 28.49 percent in terms of network longevity based on FND, HND and EPND. This increase is due to the advantages of equalized nodes distribution based on the layering concept, as well as the use of multihop transmission and WET for the nano-cluster head in the first layer along the data forwarding path.

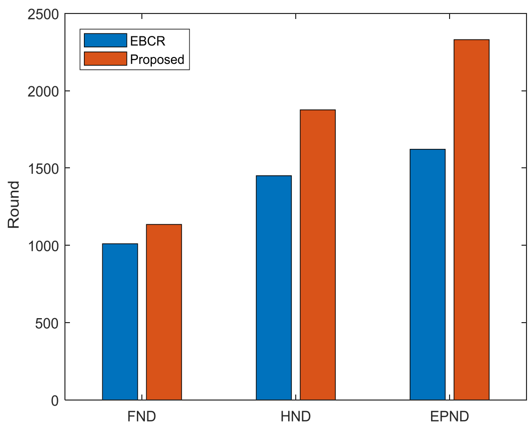

Fig. 4: Network Lifetime based on FND, HND and EPND

Average Residual Energy

Figure 5 compares the proposed protocol to the EBCR protocol in terms of average residual energy, where average residual energy refers to the average remaining energy of the nano-nodes in the network after a particular number of cycles. As illustrated in Figure 5, the energy pattern for both approaches follows the same trends. As demonstrated in Figure 5, the average energy of the constructed protocol is higher than that of the EBCR protocol at different rounds. The EBCR protocol used direct transmission between active nodes and their respective nano-cluster heads during data transfer, regardless of the node distance from the cluster head, which might have affected their communications. This demonstrates that the proposed protocol is more effective in terms of conserving network energy since multihop data transmission is not only restricted to the inter cluster phase of the network but also to the intra cluster phase.

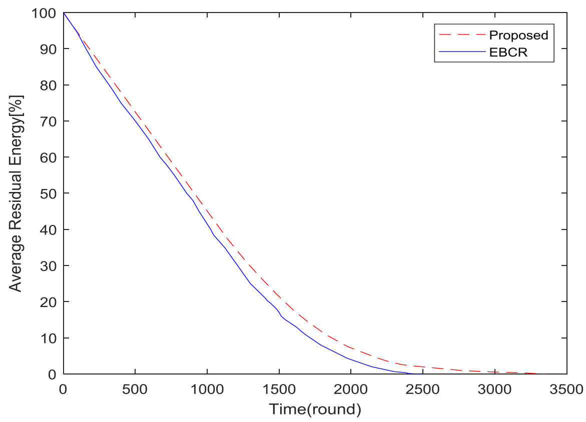

Fig. 5: Average Residual Energy

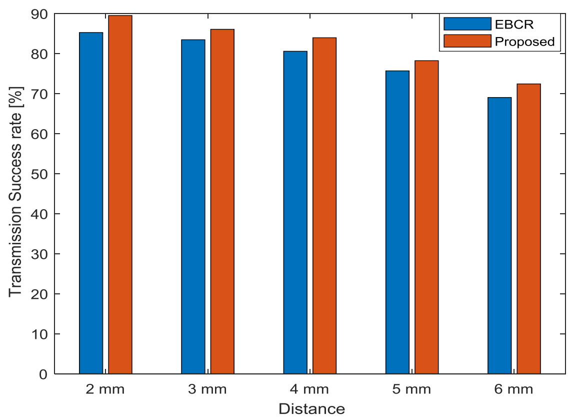

Fig. 6: Packet Transmission Success

Packet Transmission Success

The diagram in Figure 6 illustrates the comparison of packet transmission success between the proposed protocol and the EBCR protocol with respect to distance variation. It is observed from Figure 6, that the transmission success for both protocols decrease with increase in distance. This is due to the possibility that packet will be lost during frequent data forwarding towards the nano-controller as distance increase. From Figure 6, it is deduced that the transmission success of the proposed protocol is higher than the EBCR protocol at all distance. The technical reason for this is that the proposed protocol adopts a wireless energy transfer for each selected nanocluster head for enhancing data forwarding activities and minimizing packet loss.

Conclusions

The development of a cluster-based routing protocol for wireless body area nanonetworks was discussed in this research paper. Based on a concentric layer design, a clustering method with wireless energy transmission for the inner layer nanocluster head closer to the nanocontroller was developed and implemented. The performance of the developed protocol was evaluated using Matlab R2020A as a simulation tool, and the findings revealed that the protocol enhanced network lifespan while increasing data transmission success. In comparison with the EBCR protocol, the proposed protocol has high residual energy and exhibited average performance improvement of 28.49% in terms of network lifetime based on FND, HND and EPND with high transmission success.

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