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A feasibility study of cluster-based energy harvesting aware routing protocol for body nanosensor network

Sikiru. O. Zakariyya

Department of Electricl and Electronics Enigneering
University of Ilorin
 Ilorin, Nigeria
 zakariyya.os@unilorin.edu.ng

Abdulmalik. S. Yaro, Aliyu. D. Usman, Suleiman. M. Sani,
 Abdoulie. M. S. Tekanyi

Department of Electronics and Telecommunication Engineering
Ahmadu Bello University
 Zaria, Nigeria
 asyaro@abu.edu.ng, aliyuusman1@gmail.com,
 smsani@abu.edu.ng, amtekanyi@abu.edu.ng

Abstract—Wireless nanosensor network (WNSN) are networks of interconnected nano-nodes communicating at terahertz frequency. The nano-node range of communication as well as the overall performance of the WNSN is affected mainly by the path loss of the terahertz frequency band and also by the very limited nano-nodes resources and capacity. For that reason, there is need for a suitable routing protocol that will guarantee multihop communication in WNSN. Clustering technique has been proving to be a cost-effective method to provide successful communication for body WNSNs. However, the nanonode elected as the nano-cluster head diminishes its energy dynamically. This will result into loss of monitored data in the cluster and reduce the reliability of the network. Existing clustering techniques in WNSN proposed for health care application did not take the energy exhaustion of the nano-cluster head into consideration. Hence, this work gives a review of work done to date on WNSN routing protocol, identifies their weaknesses and then suggest the implementation of an energy harvesting aware protocol that employs cluster-based hierarchical architecture by considering two different scenarios (using a back-up cluster head technique and using a wireless energy transfer technique) with a view to ensuring lifetime operation of the nano-node, minimize packet loss and conserving energy.

Keywords—Backup Cluster, Nano-devices, Nanosensor, Routing, Terahertz.

I. INTRODUCTION

The emergent of nanotechnology has enabled the engineering community to develop a new set of nano-scale devices that have the ability to carry out simple operations like actuation, sensing, data storing and computing. The nano-scale devices are however limited with energy constraint and low processing capability. The limitation of energy constraint, sensing capability and data processing capability of individual nanoscale device can be overcome by interconnecting them to form a wireless nanosensor network (WNSN). It differs from the typical Wireless Sensor Network (WSN) because the nanodevices have the ability to detect events at the nano-scale. The area of Wireless Nanosensor Networks (WNSN) is attractive in many monitoring applications for civilian, biomedical and military use [1]. Different communication paradigms including acoustic, nano-mechanical, electromagnetic and molecular communication have been suggested overtime on the basis of the chosen transmission medium for WNSN. Nonetheless,

acoustic and mechanical communication is unsuitable for WNSN in human body [2 3] while molecular and electromagnetic communication paradigm have been very promising [4]. Eventually, electromagnetic communication for nano-node-nodes is expected to work in the 0.1-10 THz 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 [5]. In health care applications, communication between networks of nano-nodes implanted in the human body is referred to as Body Area Nano-Networks (BANNs) [6]. These nodes communicate with each other in the network and information is routed through a gateway to the external interface and then to the health monitoring unit. Since the medical information are critical, loss of data is crucial in this application. Hence, a routing protocol is needed to guarantee the delivery of data.

The existing information routing protocol in the WSN is not directly applicable to WNSN due to their nano-scale properties which limit the amount of complex protocol that could be run on them and also their method of harvesting energy from the environment as well as the terahertz frequency band channel characteristics. Few protocols have been developed for WNSN which have their own qualities and shortcomings.

It is more advantageous to organize the nanonodes in WNSN into clusters to minimize energy consumption of individual nodes in the network. This is achieved by selecting a subclass of the nanonodes as the nano-cluster head based on their energy. These nano-cluster heads are in charge of the cluster activities and received monitored data from their nano-cluster members. These data are conveyed to the nanocontroller directly or through multihop using another nano-cluster head based on distance [7 8]. Despite the fact that this technique can minimize the energy consumed, its main challenge is the amount of energy consumed by the nano-cluster head. The nano-cluster head will exhaust their energy quicker as they are responsible for forwarding all the data gathered in the cluster. Also, the nano-cluster head along the routing path tends to have substantial task thereby speedily exhausting their energy.

Therefore, this work gives a review of work done to date on WSN routing protocol, identifies their weaknesses and then suggest the implementation of an energy harvesting aware protocol that employs cluster-based hierarchical architecture by considering two different scenarios (using a back-up cluster head technique and using a wireless energy transfer technique) with a view to ensuring lifetime operation of the nano-node, minimize packet loss and conserving energy.

II. RELATED WORKS

Wireless nanosensor network research has received a lot of attention from the early researchers, they have surveyed and identified the concept, challenging issues, communication and networking models with energy harvesting as the only source of powering the nano-nodes. Most of the existing routing protocols designed for the WSN are not directly applicable to WSN due to the energy harvesting, terahertz channel peculiarities and limited capability of the nano-node. The focus of this work is information routing among nano-nodes that forms nanosensor networks operating in the terahertz frequency band. As such, some of the pertinent works are reviewed in this section.

Routing is a key role of the network layer of the communication protocol stack and it is defined as the process of establishing paths through one or several relays from a source to a sink (e.g. a gateway device). The routing protocols research in WSNs is still at an early stage as only a few numbers of routing protocols have been proposed [9]. In recent years, routing protocols for WSNs has been receiving attention from various researchers. Three routing protocols have been majorly identified:

- a) Flooding based protocols
- b) Proximity routing protocols
- c) Energy harvesting based routing protocols

The simplest of the above-mentioned protocol is the flood-based routing protocol as it's consistent with the nano-node energy and computation power [10]. However, flooding techniques will lead to the excessive transmission and broadcast storm which in turns increased energy consumption. In an attempt to improve the performance of flooding-based routing protocol, proximity routing protocol which controls the number of neighboring nodes was proposed. Some of the reported proximity protocols include CORONA [11 12]. CORONA categorized the nodes in the network into an anchor node and user nodes where the anchor nodes are assumed to have high processing capability than the user node. While CORONA is effective for point to point communication, terahertz channel attenuation characteristics were however not considered. In an effort to solve the problem associated with CORONA, EEMR protocol was proposed [12]. However, nano-nodes failures as a result of energy exhaustion or interruption in the transmission link due to channel environment not solved by the protocol. The last category of the above-mentioned routing protocol designed specifically for self-powered nano-nodes is the energy harvesting based routing protocols. The main goal of the energy harvesting routing protocol is to balance the harvested and the consumed energy by the nano-nodes in the WSNs to achieve perpetuity. The first routing framework proposed for WSNs based on energy harvesting

considered the tradeoff between harvested and consumed energy and also establish multi-hop routing based on features of terahertz channel [13]. They employed the usage of hierarchical routing architecture with clustering where each nano-node forwards their information to the nano-controller via their cluster head. It was revealed from simulation that the protocol can increase the throughput as well as reduce energy consumption. Nevertheless, this routing protocol has a high computational complexity which may hamper its use in practice. In an effort to integrate the Body area nanonetwork (BANNET) and a macroscale health monitoring system, an energy harvesting routing protocol based on Hierarchical network architecture that regulates communication among nano-nodes was proposed [14]. They proposed two separates energy harvesting aware protocol stack (greedy and optimal approach) which are both made up of MAC and Routing algorithm. However, the developed protocol did not achieve big and meaningful performance gain as in relation to the flooding scheme due to the handshaking mechanism. Reference [15] proposed a wireless nanosensor network model based on On-Off Keying (OOK) protocol and TDMA framework for intrabody disease detection. Based on the fact that the nano patch antennas are graphene-based in a honeycomb crystal lattice, the author assumed a hexagonal cell-based nanosensor which was deployed in a cylindrical shape 3D hexagonal shape. However, they did not consider the energy harvesting process of the nanosensor node. Reference [16] proposed an efficient scheme for data collection in a Body Area Nanonetwork. The proposed scheme which is largely determined by the distance between the nano-nodes and nano-router aimed at improving the work of [14] by taking the transmission path loss into consideration. However, if a nano-node is outside the coverage range of any nano-router, it waits pending the time when a signal can be received by one of them which results to delay. In order to improve the performance of nano-nodes communicating at terahertz frequency, an energy-conserving routing method using a hybrid cluster with centralized scheduling was proposed [7]. NANO-SIM was employed in simulating the ECR scheme and the performance was evaluated in terms of outage probability, outage capacity and energy efficiency. It was reported from the simulation result that the ECR scheme balance the energy consumed in WSNs and also reduce the data collision due to the multilayer topology and transmission time allocation. However, consideration is not given to failure of cluster head which might results into loss of data packets. However, a reasonable mechanism for updating the cluster head is not provided. Finally, energy balanced routing protocol for intrabody wireless nanosensor network was proposed [8]. Intra cluster transmission between nano-nodes and cluster head is in a cluster is achieved using one hop while the multihop transmission is used between cluster head and the nano controller. However, consideration is not given to failure of cluster head which might results into loss of data packets.

Considering the similar work reviewed, a summary of the drawbacks includes:

- a) The use of routing protocol that doesn't consider the energy harvesting of the nano-nodes which renders the protocol unrealistic for nanosensor networks with limited energy as in the work of [15].

b) The use of the protocol with a high computational complexity which prevents their large usage in WSNs as in the work of [13].

c) The development of protocols not applicable to health monitoring applications as in the work of [10 11].

d) The development of health monitoring protocols that assume communication is initiated from the external body thereby omitting the critical information detected by the nano-nodes implanted inside the body as in the work of [14 16].

e) The development of a protocol that does not consider the drop in the energy level of cluster head below the required energy prior to inter-cluster transmission as in the work of [7 8].

III. DESIGN METHODOLOGY

Due to the problems identified in the existing work, this paper proposed a system which comprises of nano-nodes implanted inside the human body forming a nanosensor network. The nano-nodes which are energy-constrained are capable of communicating with each other and the outside world. The implanted nano nodes forward their available data through a cluster head to the nano-controller which has more energy and computational resources. The nano-controller forwards the data via the nanointerface to the external world via a gateway. Hierarchical clustering approach will be implemented where each node is grouped into a certain cluster and a cluster head is appointed based on available energy and the designed scheme. The nodes in a cluster are referred to a nano-cluster member. Each nano-cluster member communicates directly with the cluster head or through another cluster member based on the required energy to transmit. The cluster head can either communicate directly to the nano-controller or through a neighbouring cluster head using multihop communication. In a situation where the energy level of the nano-cluster head is below the required energy to complete inter-cluster communication, two solutions are proposed to prevent loss of data in the network as depicted in Fig. 1 and Fig. 2. Fig. 1. shows the back-up clustering technique. In this scenario, those cluster head with deficient energy below the energy required to complete inter-cluster transmission will hand over the gathered data in the cluster to the preselected back-up cluster head (BC). Doing so, the system will prevent the loss of gathered data in the cluster and hence improve the reliability of transmitted data. Fig. 2 depict the conceptual diagram of clustering with wireless energy transfer technique. In this scenario, we employ the concept of wireless energy transfer from a more resourceful nanocontroller to energy deficient cluster head. Prior to data transmission, the cluster head with remaining energy below the required energy for data transmission will receive additional energy from the nanocontroller wirelessly. This will prevent the cluster head from losing gathered data in its cluster as a result of low energy. The nodes activity will be categorized into Active, Listening, blocking and sleeping modes in order to effectively manage energy resources. Transmission of data will be based on TDMA where time slot will be allocated to each cluster layer based on request. Data will be classified as either emergency or regular data. To the best of our knowledge, the concept of back-up clustering and wireless energy transfer from a more resourceful nanocontroller has

not been considered in the domain of WSN, hence the novelty of this work.

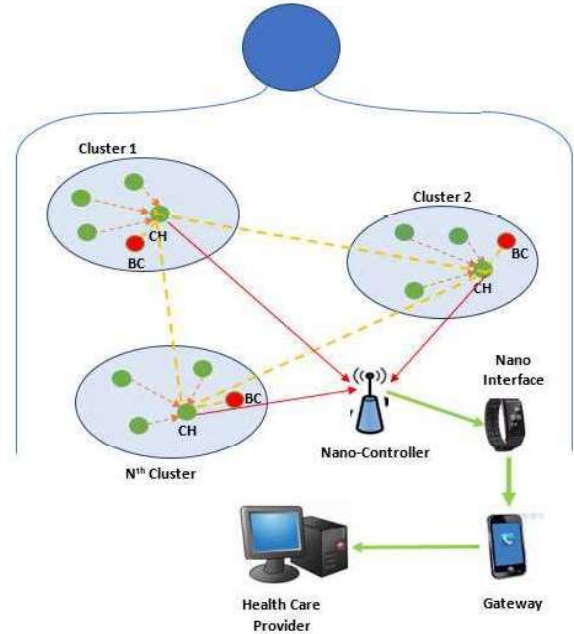
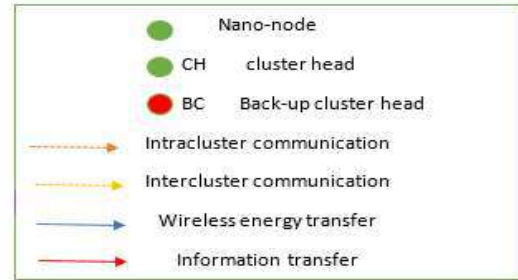


Fig. 1. Conceptual Framework for the proposed work using a back-up cluster head



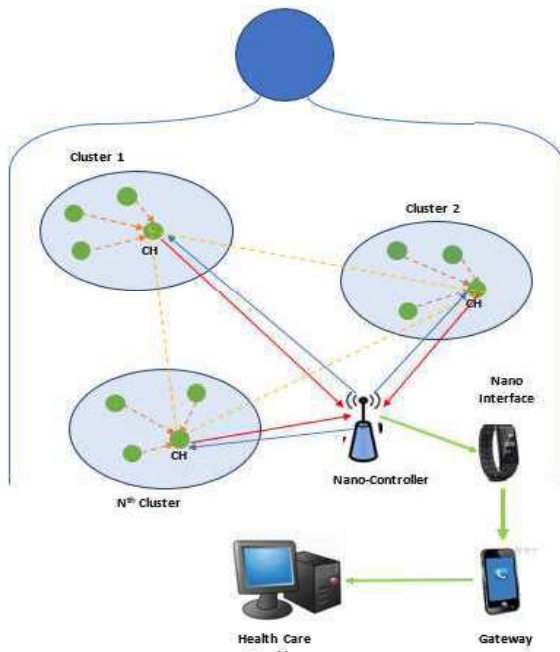


Fig. 2. Conceptual Framework for the proposed work using wireless energy transfer

IV. CONCLUSION

This paper presented the state of the art routing protocol developed for WSNs. First we discussed the problem and constraint of WSNs and the unsuitability of directly applying the existing information routing protocol in the WSN to the WSN. Then we surveyed the existing protocol design for WSN and identified their drawbacks. We then presented the idea of back-up clustering and wireless energy transfer which is expected to improve the data packet transmission success, minimize energy and improve network lifetime. The current work in progress is the implementation and simulation of the proposed ideas.

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