# A Routing Protocol for The Wireless Body Area Sensor Network (WBASN)

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*Abstract*—**Due to the fact that nanonetworks'sensors are globally limited in their range of communication of processing power and their modeling and implementation of energy capacities , design and implementation of routing algorithms are considered a nontrivial task. In this paper, we propose an enhanced energy-efficient algorithm (E3A). E3A is a cognitive data delivery approach that addresses the challenges of data delivery in IoNT networks. The proposed approach caters to the grid-based distribution of the employed nanosensors on the monitored object/body organ to efficiently and effectively cope with the dynamicity of nanonetwork topology . The rest of the paper is organized as follows. Section 2 reviews previous related studies. Section 3 discusses our system models. Section 4 describes our proposed routing approach for IoNT paradigm. Section 5 provides performance evaluation for the proposed approach. Finally, Section 6 provides the conclusions and future directions.**

*Index Terms*—**Internet of Nano-Things (IoNT), Routing, nanonetworks , communication layer stack.**

## I. Introduction

THE wireless body area network (WBAN) is a network that provides continuous monitoring over or inside the human body for a long period and can support transmission of real-time traffic, such as data, to observe the status of vital organ functionalities [1]. This technology has found great interest in health and infrastructure monitoring; and investigations in it are still ongoing. Moreover, WBAN inception has provided enhanced and efficient solutions to various applications in biomedicine, industry, agriculture, and military applications that rely on nanotechnology science. The field of Internet of Things (IoT) has been continuously growing, especially in the past decade. Furthermore, many technological advances have been reached in the field of nanotechnology. Combining both these fields (Internet of Things and nanotechnology), a new field termed as the Internet of Nano-Things (IoNT) has emerged. Intelligent, energy-efficient, and trustworthy wearable nanodevices can dramatically enhance and transform the human experience and interaction and perceive the world around us. However, there are certain difficulties, both conceptual and technical, that need to be traversed before this IoNT paradigm can be realized in our daily lives. One of the main areas that this technology has been used in is the area of healthcare. Where systems for monitoring the internal well-being of the human body have been developed, these systems usually employ a vast number of nanosensors embedded in the human body which continuously communicate with each other and with the outside environment, forming the WBAN. For example, nanosensors which can monitor the glucose level of the blood have been developed for the protection of diabetes patients or possible diabetes patients [2]. Furthermore, magnetic nanosensors for the detection and profiling of erythrocyte-derived microvesicles have also been used [4]. The successful implementation of such a technology will make the monitoring of the individual health much easier by offering an all-time low-cost monitoring system. Several IoNTs' design aspects, which stem from their unique features in terms of limited-energy constraints, short communication range, and low processing power, needed to be incorporated into their routing protocols in order to realize the IoNT paradigm. Different challenges against routing protocol design in terms of energy are still being investigated with no currently fully developed solutions. Nanonetworks consume energy in almost all processes. They consume energy while making data transmission, data sensing, and data processing. There have been a few attempts towards achieving energy efficiency in such networks via wireless multihop networking [2–5]. However, such schemes either assume static network topology, which renders these schemes impractical for real-life network implementation, because nanonetworks exhibit random topology due to the mobility of nodes, or are restricted to two-hop from source to the sink routing schemes. Due to the fact that nanonetworks'sensors are usually limited in their processing power, communication range, and energy capabilities, design and implementation of routing algorithms are considered a nontrivial task. In this paper, we propose an enhanced energy-efficient algorithm (E3 A). E3 A is a cognitive data delivery approach that addresses the challenges of data delivery in IoNT networks. The proposed approach caters to the grid-based distribution of the employed nanosensors on the monitored object/body organ to efficiently and effectively cope with the dynamicity of nanonetwork topology [6].

The rest of the paper is organized as follows. Section 2 reviews previous related studies. Section 3 discusses our system models. Section 4 describes our proposed routing approach for IoNT paradigm. Section 5 provides performance evaluation for the proposed approach. Finally, Section 6 provides the conclusions and future directions.

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## II. Related Work

The communication in nanonetworks can utilize one of the following technologies; nanomechanical, acoustic, electromagnetic, and chemical or molecular communication [8]. Mainly due to their tiny sizes, nanonetworks introduce difficulties in both hardware and software design. Especially for the software part, the communication layer stack needs fine tuning as such tiny hardware imposes critical restrictions. Knowing that the physical wireless signaling is performed at THz bands, due to the restricted antenna size, this necessitates special routing/communication techniques [9].

Routing protocols in nanonetworks can be classified into simple flooding and random point-to-point protocols. These protocols can be optimized and customized for more efficient performance. However, several design aspects shall be taken in to consideration, such as the nanonetwork topology, nodes' mobility, deployment space (2D vs. 3D), and energy. In fact, energy is the most significant and limiting factor according to current nanotechnology studies [2]. In that sense, routing protocols, which optimize the energy consumption in nanonetworks while satisfying different constraints, are expected to have a great influence on the IoNT paradigm. Existing routing approaches in nanonetworks aim at extending the network lifetime by minimizing the energy consumption while considering traditional metrics which might not be effective in practice. In [16], authors proposed a peer-to-peer routing protocol. In their work, 2D uniform grids and 2D uniform random topologies are assumed, in which identical nanosensors are deployed. Packet collisions and redundant retransmissions are the only two metrics that have been considered while optimizing the proposed protocol. In this protocol, nodes are classified based on the packet reception statistics they have logged. The routing scheme exploits this classification in optimizing energy consumption. In [17], coordinate-based addressing scheme is proposed for nanosensors distributed uniformly in a rectangular 2D topology. The proposed routing protocol tries to minimize the hop count of the packet transmission by placing anchor nodes at the vertices of the grid. This routing protocol is assessed by considering packet retransmission rate, successful packet reception rate, and packet loss rate. In [18], channel-aware routing protocol is proposed. Authors considered the special attributes of the THz band communication. The forwarding is optimized by considering two cost factors: namely, avoiding long-distance region in which the signal may suffer the path loss and avoiding short-distance region in which the number of hops can be increased dramatically. However, their achieved results are based on simple 1D simulations. Authors in [19] focused on the physical layer part for their routing protocol. They proposed a physical network coding routing protocol by extending a geographical greedy routing algorithm for nanonetworks. The packets are separated into two parts and transmitted in pairs along pipelined multi-hop route, while avoiding grouped weak nodes to achieve energy effectiveness. The work presented in [20] proposes a geographic routing protocol; nodes of the nanonetworks are assumed to comprise two types of anchors, which have higher communication and processing capabilities than the edge nodes. Edge nodes are required to localize their positions in order to reference these anchor nodes. The authors assume that the network topology is square with four anchors located at the corners. Their routing approach operates in two phases: the setup phase and the operation phase. The setup phase is designed to assist the network edge nodes in measuring their distances from the anchors. In the operation phase, a source node selects anchor nodes and incorporates this information in transmitted packets' headers. A receiving node checks its location, the destination location, and the source location to decide on forwarding or dropping the packet. However, this approach requires addressing for all nodes, which forms a significant challenge in the IoNT with nanoscale applications. The work in [22] presents a flooding data dissemination scheme. The proposed scheme assumes a square grid network architecture where the nanosensors are distributed densely at the vertices of the grid. Utilizing the uniform nodes' patterns and lattice algebra, the scheme dismisses the requirement for node addressing and employs a simple flooding routing scheme for data dissemination. The scheme relies on classifying each node as either an infrastructure or single user node, depending on its reception quality. Based on the previously discussed attempts in the literature, we can conclude that energy-aware routing protocols aim at identifying the shortest path and/or the nearest neighbor towards destination in the nanonetwork. In the nearest neighbor approach (NNA), when a packet is transmitted from one node to another, it follows the shortest path [13]. NNA assumes that if a packet always follows shorter path, it will use shortest path until it reaches destination node. In short, this algorithm uses four-direction transmission (left, right, up, down) only in virtual grid setups, where the closest vertical/horizontal but not diagonal relying neighbor is used to send the data packet [14]. As a result, the hop count can unnecessarily increase and also the energy consumption is negatively affected by increased hop count. Meanwhile, in the shortest path approach (SPA), when a data packet is transmitted from a node, it calculates the shortest path from the sender node to the destination instead of the node-to-node fashion. Accordingly, SPA uses eight-direction data forwarding (up, upper-left, upper-right, down, down-left, down-right, right and left), and thus, it considers the shortest path to destination rather than shortest neighbor to relay. Nevertheless, nanosensors in the targeted IoNT can typically follow a random behavior. They can move around the human body for certain health applications, and therefore, may need to be associated with varying neighbors frequently, and hence, may not always have a fixed network structure/topology. In this research, we proposed a rational data delivery algorithm (RDDA) as a distinguished routing protocol for the IoNT. It assumes a multitier nanonetwork and cluster/tierwide synchronization. Moreover, it's a topology-independent protocol which copes with the randomness nature in nanonetworks. According to RDDA, the system determines the path from the routing node (RN) to the destination node in view of each node's remaining energy. The remaining energy of recent RN's neighbors is controlled each time before a data packet is sent from the RN. If one of these neighboring RNs' energy is below half of the initial energy, a new alternative path will be determined and the data packet will be forwarded accordingly. Although this can increase the hop count in comparison to SPA, the energy efficiency will be improved and network lifetime will be prolonged.

## III. System Models

In this section we list the assumed system models for the proposed E3A approach toward prolonged lifetime in IoNT.

### A. Network Architecture

With the networking technology, nanosensors have more potential, since they can cooperate and communicate to achieve more challenging tasks. Figure 1 shows

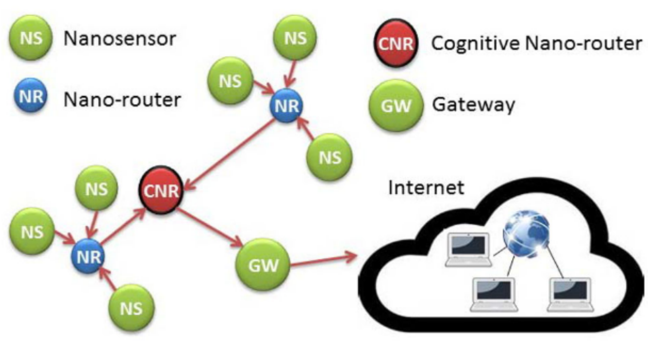


Fig. 1. Network architecture and main components in the IoNT.

the general network architecture to be assumed in this paper for the vision of the IoNT paradigm. Significant elements of the nanonetworks are the nanosensors, NRs, and cognitive nanorouters (CNRs). Nanosensors are the smallest and simplest nanodevices. These devices can only perform simple computation tasks and can transmit over very short distances due to limited energy and memory and reduced communication capabilities. NRs have slightly larger computational resources than nanosensors, and thus can aggregate information. CNRs, also called nano-micro interfaces, are used to further aggregate the information forwarded by the NR and send them to a micro-scale device. And thus, CNRs are hybrid devices which can communicate in the nanoscale and can utilize classical communication paradigms in micro- and/or macrocommunication networks. Though GWs these types of networks can be connected to the traditional Internet. The communication range in IoNT is predicted to be between 1 nm and 1 cm in terahertz-band [24]. And thus, multi-hop routing is an effective data delivery style. Moreover, the direction of a communication route is not deterministic and depends on the drift velocity of nanosensors, which may result in service disruption and extended delays [25].

### B. Lifetime in IoNT

Lifetime in this research is defied as the time or number of transmission rounds in which the nanonetwork can no longer send useful information to the end users. It is reflected by the network's inability to find a path to deliver data with satisfactory values for a number of QoI attributes such as latency, fairness, and remaining energy [21].Therefore, we can evaluate the lifetime of the nanonetwork in the IoNT by either counting the alive nanosensors [26], checking the ratio of still-covered areas to the uncovered ones by the nanonetwork, or based on both [27].

### C. Energy Conservation and Dead Node Issue

Energy in nanonetworks can be a critical factor towards realizing the main objective of the emerged IoNT paradigm. Knowing that majority of the nanonetwork energy budget is spent on routing data, we focus this study on the NR energy expenditures. According to [24] this can be characterized by the following equation.

$$E_{N\,R} = C\left(T\ *\left(E_{T\,X}\right) + R\ *\left(E_{R\,X}\right)\right) \tag{1}$$

where $E_{T\,X}$ and $E_{R\,X}$ are transmission and reception energy, respectively. $C$ indicates the cost function of the energy consumed, and $T$ and $R$ are the number of transmitted and received packets, respectively. As discussed earlier, the main function of CNR is data aggregation and routing of traff received from the NRs. Therefore, it is expected that CNRs consume additional energy compared to regular NRs. This energy consumption can be characterized as follows:

$$\mathrm{E}_{C\,N\,R} = C\left(T\ *\left(E_{T\,X}\right) + R\ *\left(E_{R\,X}\right)\right) + C\left(A\ *\left(E_{a\,g}\right)\right) + C\left(P\ *\left(E_{c\,g} - E_{p\,m}\right)\right) \tag{2}$$

In Eq. (2), $A$ and $P$, represents the total number of packets that are aggregated and processed by the cognitive nanorouters, respectively. $C\left(A\ *\left(E_{e_z}\right)\right)$ shows the energy cost during data aggregation, and $C\left(P\ *\left(E_{\alpha_g} - E_{p\,r\,o}\right)\right)$ reveals the energy cost due to protocol and processing overhead while performing cognitive (rational) processes. By forming Eq. (2) in terms of the energy cost of $NRs$ we obtain:

$$\mathrm{E}_{C\,\mathrm{VR}}\ \geq\ E_{N\,R} + C\left(A\ *\left(E_{\mathrm{g}}\right) + C\left(E_{\alpha_{\mathrm{g}}} - E_{p\,v}\right)\right. \tag{3}$$

If the NR and CNRs use the same transmit power, the equality sign becomes positive in Eq. (3). In this study, we assume multi-tier NRs' distribution. Once all the fist tier NRs are dead, no other node will be able to send data to the GW, and the lifetime of the network will be over.

## IV. Enhanced Energy-Efficient Approach

In this section we propose a novel energy aware data delivery approach for the energy-constrained IoNT, namely the E3A. Data delivery decisions in the E3A are based on observing the dynamically changing topology of the network. Since the learning process might be too slow to respond/converge before further changes take place in the network, we choose a heuristic search strategy, called AHP, to aid in making quicker decisions that suit the randomly deployed nanosensors. With the help of a model of the original network topology combined with the currently observed changes, we make use of the AHP heuristic algorithm [11] to identify the nodes that can be used for data delivery to the sink (GCN). This approach is useful when a problem is to be solved repeatedly with the same goal at GCN, but with different initial states at CRNs. In the AHP algorithm, RNs and CRNs are initially assigned heuristic values at the time of deployment based on their proximity to the sink. Nodes that lie at one-hop distance to the sink have the highest probability of successful data delivery to the sink. Hence, they are given the highest heuristic weight (0.1 in our study). Nodes lying further away from the sink are given lower weights (0.05), so that they have lesser influence on the heuristic decision-making. However, they are not assigned a zero weight, because these nodes will still be able to participate in multi-hop routing in case the nodes with direct access to the sink become unavailable due to poor link conditions, network congestion, or node deaths. The higher the weight of the heuristic, the higher will be the chance that the node will be chosen for data transmission to the sink. These values remain field at each RN and CRN until the nodes die, at which time the heuristic values are made "0" as they do not influence the heuristic decision anymore.

### A. Learning

Learning is used in our E3 A approach in order to determine the most appropriate paths towards the GCN that satisfy the nanonetwork requirements. This cognition element uses a direction-based heuristic to determine the data delivery path through RNs that lies in the direction of the GCN. Hence, each time a CRN has to choose the next hop, the direction-based heuristic eliminates RNs that increase the distance between the current RN and GCN. Knowledge of the positions of the CRN and its one-hop RNs is used by the heuristic to determine the set of such RNs, which we call forward-hop RNs. Thus, the forward-hop RNs of a CRN identified by the direction heuristic is constituted by those RNs that reduce the distance between the CRN and the GCN. This information is stored in the CRN for use in the next transmission rounds. Thus, the direction-based heuristic, along with feedback from the network about the chosen paths, helps the CRNs to learn data delivery paths to the sink as the network topology changes.

### B. Reasoning

In the E3A approach, we assume a modified version of the analytic hierarchy process (AHP) [26] for implementing the reasoning element of cognition in the IoNT. AHP supports multiple-criteria decision making while choosing the data path. For example, if we have delay-sensitive data, the node which provides the lowest latency will be chosen even though it might degrade other metrics such as the network energy or throughput. If two next-hops guarantee the same latency, then the next attribute to compare will be energy, and then throughput, assuming that energy is the next desired attribute in the nanonetwork. AHP provides a method for pairwise comparison of each of the attributes and helps to choose the node that can provide the best network performance in the long run. The following subsequent example has more details on the utilized AHP. While AHP calculations help in deciding the next-hop, it also helps in planning for future actions. The CRNs are able to store the calculated values of the nanonetwork attributes, which can be used in future transmission rounds. Hence, these values are not necessarily calculated at every transmission round.

## V. Performance Evaluation

In this section, we evaluate the performance of the proposed E3A. We use SPA and NNA algorithms as baseline evaluation algorithms. Based on the aforementioned system models, we summarize these two baselines' categories as follows

### A. Shortest Path Algorithm (SPA)

The first baseline category in this research is the SPA. As we mentioned before, it is one of the most well-known works in routing. It is used in two cases:

- **Case 1**, polling, when GCN requesting a packet from sensor nodes. In this case, the GCN randomly chooses one RN and adds the index of RN to the request package. If the range of GCN covers the selected RN, it sends the request packet directly to this RN. If not, it sends the request packet to the RN that is nearest to the target RN. Then from that RN, the packet is transmitted to the RN that was selected originally. The first baseline category in this research is the SPA. As we mentioned before, it is one of the most well-known works in routing. It is used in two cases:
- **Case 2**, pushing, occurs when the data packet is transferred from nanosensors to the GCN. The aim is to transmit the data packet to the nearest RN that is in the range of the GCN. With this routing approach, the shortest path is calculated and after that, data packet is hopped from the current RN to the next one. When the packet reaches to the RNs near GCN these RNs transmit the packet back to the GCN.

### B. Nearest Neighbor Algorithm (NNA)

The NNA approach is one of the previous works which has been designed mainly for wireless sensor networks and also is an efficient version of the shortest path algorithm. This approach calculates the shortest path but the transmission has to be occurred only towards up, down, left or right directions. In short, there is no diagonal moving, so this surely increases the hop counts, and this justifies the increment in energy consumption. In the aforementioned two baselines, SPA represents a straightforward approach in cutting down unnecessary energy consumption while choosing the shortest path. On the other hand, NNA chooses one of the RNs that has a non-diagonal connection. Using NNA increases hop count, so energy consumption is increased and network life time is decreased. The neighbor RNs' energy level and distance from GCN are compared in E3A. It chooses RN, which meets the requirements for transmission and maintains the most energy-effient topology by applying the AHP algorithm for the prolonged network lifetime. It is typical to have a deterministic placement for the RNs in bio-inspired applications where a specific area of the skin is targeted, for example, and these nanodevices are planted [29]. However, the selection of which RN to route the sensed data through varies based on the utilized routing algorithm. Thus, we compare our proposed E3A routing algorithm with both NNA and SPA in this research. A detailed description of our experimental setup is given in the following section.

### *C. Simulation Results*

In order to limit our search space, we assume a virtual grid, where SNs are placed on the grid vertices. We assume up to 1500 total SNs communicate with one GCN via 36 RNs. We used NS3 as a simulation tool for this purpose. The simulation is processed in three platforms, which are Windows, Linux, and OSX for validation purposes. We executed our simulation 100 times for each experiment and plotted the average results. More details about our assumed simulation parameters are summarized in Table I.

TABLE I
SIMULATION PARAMETERS AND VALUES [25, 29]

| *Parameter* | *Value* |
|---|---|
| *Target area* | 10 mm × 10 mm |
| *Number of nodes* | *SNs* : 100, RNs : 16, GCN : 1 |
| *Communication range* | SN : 142 nm, RN : 300 nm, GCN : 500 nm |
| *Initial energy* | SN : 31 p *J*, RN : 110 pJ, GCN : *Unlimited* |
| *Energy consumption* | SN *and RN* (*Receiving*) : 31.2 p / bit<br>SN *and* RN (*Transmitting*) : 53.8 p / bit |

In this study, we are interested in examining the nanonetwork performance when the size of the nanofunctional devices goes down to milli/nanoscale. Accordingly, a tissue cube is assumed for the considered bio-applications, since the tissue size (10 mm × 10 mm × 10 mm) is comparable to THz wavelength [26]. As we mentioned before, we assume 36 RNs (0.1 mm3 each) and 1 GCN in the area of 10 mm × 10 mm. GCN has bidirectional connection with the closest RNs to GCN, which are RN14, RN15, RN20, and RN21. Also, GCN has unidirectional connection with rest of the RNs which are in range of GCN.
Analysis based on the depicted deployment in this study shows that during the network lifetime, paths from a source RN to the GCN changes according to RNs' remaining energy based on the E3A. As a result of this, the network topology and hop count randomly change and there is no conclusive hop count for E3A. Thus makes our proposed approach more adaptive to dynamic topologies in the IoNT.

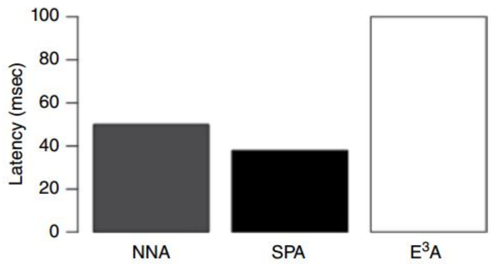


Fig. 2. Comparison of latency.

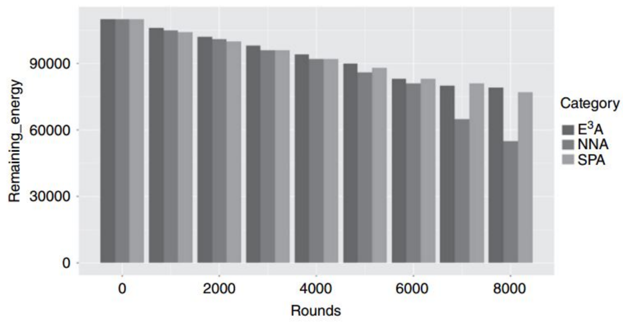


Fig. 3. Comparison of average remaining energy level at RNs vs. total transmission rounds.

We remark also that hop counts are related mainly with the packet delay rate, so more hop count values mean more delay. And hence, we can filed latency time for these three approaches in Figure 2. It is clear that E3A has higher latency in comparison to the other baselines. The reason for that is because it determines the route the packet should follow according to the energy ratios of the nearest RNs. The routing approach which has the least latency time is SPA. On the other hand, we plot the average energy levels per round in Figure 3. It is clear that E3A is more efficient than both SPA and NNA in terms of lifetime. E3A saves more energy than SPA and NNA algorithms. In Figure 4, the bar chart shows the network lifetime according to the three stated algorithms. The X-axis shows algorithm type while the Y-axis shows network lifetime in seconds for the aforementioned network topology and values. While NNA and SPA have the same lifetime, E3A has more lifetime than these two algorithms. In addition, network lifetime also depends on the GCN's request time. The line chart in Figure 5 shows different request times in seconds, and their effect on the network lifetime according to the different routing techniques: E3A, SPA, and NNA. The Y-axis indicates network lifetime and the X-axis indicates request time. As the packet request intervals of GCN increase, the network lifetime normally also increases. The reason for the difference in graph is the algorithms' durability against energy spending. Although NNA and SPA have same lifetime, E3A has extended lifetime in comparison to these two algorithms. In Figure 6, the Y-axis represents the energy level of specific RNs and the X-axis represents the specified RNs and the algorithm types. When we compare the one-hop RNs energy level with respect to these algorithms. E3A increases

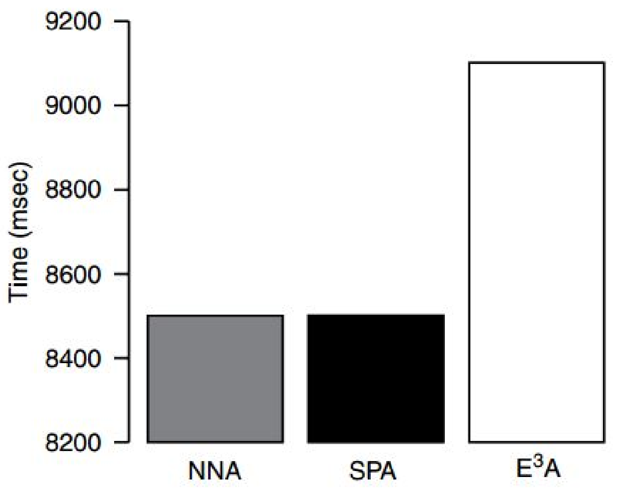


Fig. 4. Comparison of network lifetime (msec).

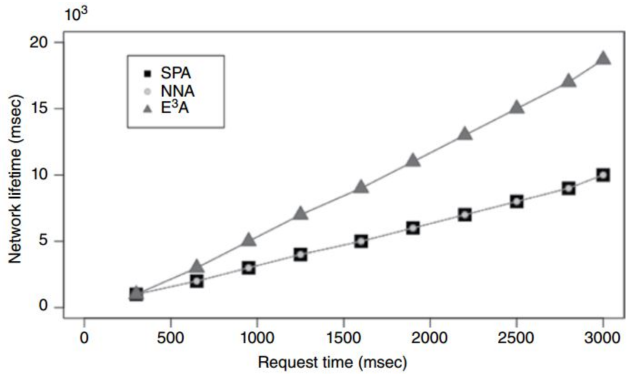


Fig. 5. Comparison of network lifetime vs. the request time (msec).

the network lifetime and it is better in energy saving. When we compare these algorithms in terms of the number of transmission rounds, it can be clearly observed from the simulation results in Figure 7(a) that E3A outperforms NNA and SPA. That is because of the lower failure rate experienced while applying E3A, as shown in Figure 7(b), where the number of failed transmissions from E3A is lower than the others by at least 10%. Consequently, by looking at Figure 7(c), we can see that if conditions are same (e.g. same number of processed requests), our approach outperforms the other approaches with the same percentage. Since Figure 7(c) demonstrates the quantity of effective successful transmission rates for each routing technique, we can conclude that our E3A approach outperforms the other two approaches, and this makes it a good candidate for nanonetworks in bio-inspired applications.

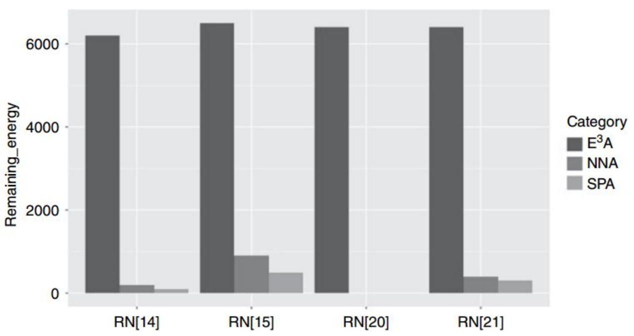


Fig. 6. Comparison of one-hop RNs' energy level.

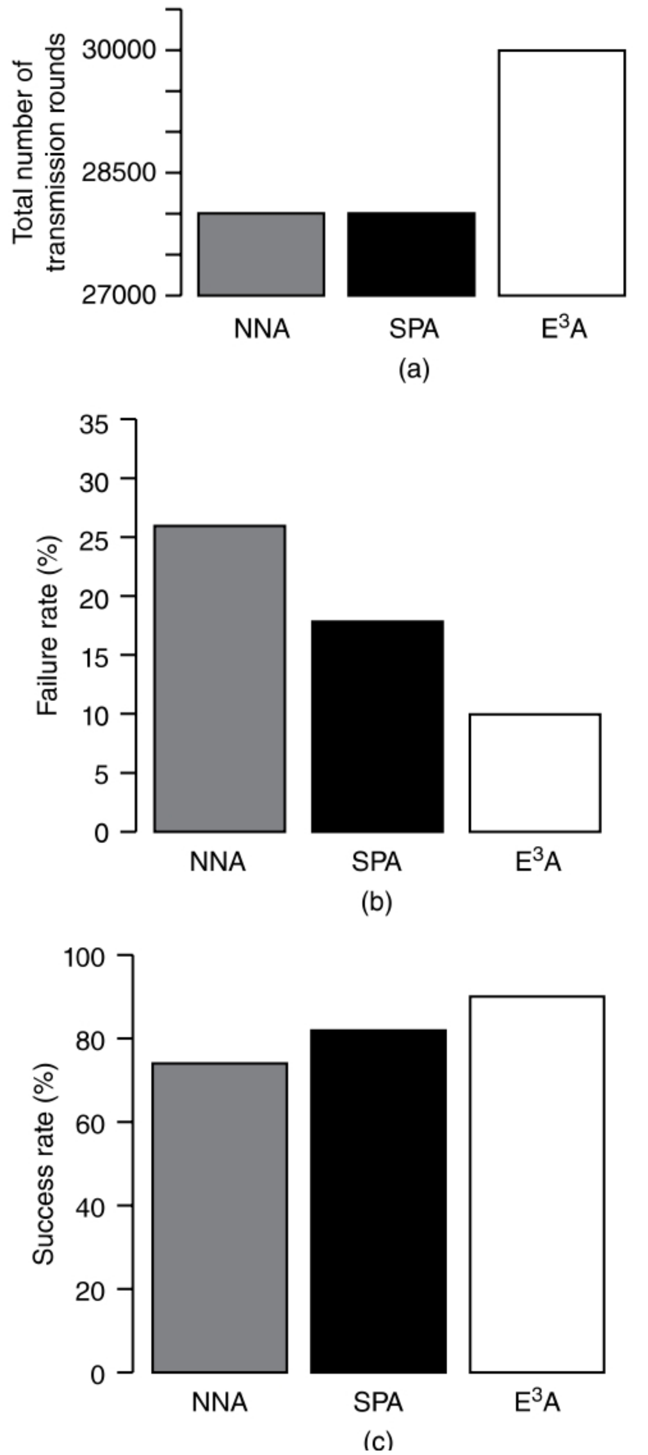


Fig. 7. (a) Comparison of the data delivery techniques based on total number of transmission rounds. (b) Comparison of the failure rates. (c) Comparison of the number of successful transmission rate.

## VI. Conclusions

In this paper, we investigated routing techniques for the IoNT paradigm in terms of energy consumption and hop counts. We proposed a novel approach for nanonetworks in IoNT, called E3A. We found that

SPA and E3A save considerable amount of energy. We conclude that the nanonetwork lifetime has inverse proportion with the number of hop counts. Moreover, we showed how the hop counts can be used to illustrate instantaneous delays and average delays of the nanorouters. Furthermore, we showed how the E3A algorithm provides the longest network lifetime. Both SPA and E3A are efficient in terms of transmission and energy consumption, but the overall results show that E3A outperformed the other two baseline algorithms.

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