Anchor Pair 4 : Addressing and Routing in 3D Nanonetworks

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Abstract

Nano-scale wireless communication faces unique challenges because of the low hardware capabilities and the limited power supply of the nanonodes, also the channel conditions are unreliable. Considering these conditions, this paper introduces three new routing schemes for 3D nanonetworks. The proposed schemes are based on multi-hop routing and offer scalability. The addressing information of the nodes is trilateration-based. In this paper we present routing schemes that use low complexity calculations to match the restrictions of the nanonode cpu and power supply. The simulations show low packet retransmission and packet loss rate, resulting less network traffic.

Introduction

- A nanonetwork consists of a lot of small wireless nodes with nano-scale components.
- One of the biggest challenges is the power supply, but our approach is focuced on packet routing and node addressing. So we assume a sustainable source based on energy harvesting.
- By studing 2D ad-hoc nanonetworks, and based on CORONA routing scheme [20] we developed new routing algorithms for 3D nanonetworks [21].
- CORONA uses a pair of two "special" nodes called "anchors" to compute the routing path. The selection of more than two anchors on 2D topology would mean that at least two anchors would have been placed on diagonally-facing vertexes. This disallow the communication between certain network areas. However in 3D routing algorithms we use three anchors because the the 3rd dimenssion (height) has to be considered on the routing path calculation. Also in 3D space the limitation of the two anchors selection does not apply.

- We decided to make some more experiments by selecting four anchors for the same calculation, the outcome was a better routing algorithm because of the more accurate computation of the routing path.
- The selection of more than four anchors would have more different combinations, resulting to high computation complexity.
- We followed a virtual position tactic which led to a more generic algorithm. So it's easy to be implemented at various topologies with different layouts.

Related Work

Nanonetworking is a topic of research interest by two main fields. The first approach is based on the biological or bio-inspired communication. For example, a piece of information can be encoded on several biological molecules (eg RNA) and diuse them to their enviroment, or mimic the operation of viruses by exchanging data upon collision [3, 22]. The second approach which is assumed in the present work, relies on wireless electromagnetic (EM) communication [11]. Related researches have so far focused on the physical (PHY) layer and the Medium Access Control (MAC) denition, with their main concern being energy effciency.

Physical Layer

- The most promising approach for the electromagnetic communication is the Teraherz Band (0.1-10.0 THz) [10].
- The proposed method to develop an antenna at nano-scale, while keeping its operating frequency high is using a new material called graphene [3].
- 0.1-0.54 Thz window can minimize the molecular absorption and increase the range of communication [5].
- Nanonode power supply can be based on energy scavenging by using piezoelectric nanogenerators, achieving a maximum of 1 packet per 12.5 sec [11].
- Some studies consider ad hoc networks of identical nodes such as the Rate Division Time Spread On-O Keying (RD TS-OOK) which is proposed as a modulation scheme in nano-communication [12]. A logical "1" is transmitted as a femtosecond-long pulse and a logical "0" is encoding as silence.

Mac Layer

- Hierarchical networks, where more powerfull nodes (routers) control the smaller nanonodes. Body area network (BAN) applications [18].
- Handshake based MAC protocol PHLAME [12].

- ReceiverInitiated Harvesting-aware (RIH-MAC) assumes that only when a node has proper energy level to be able to receive a data packet, it notifyes the interested senders with a RTR signal [16].

- Clustering-based approaches assume that the nodes are clustered in groups and they communicate through their more powerful cluster masters (controllers).

Network Layer

The performance of wireless nanonetworks can be affected not only from the routing method but also by the forwarding scheme. Recently the authors in [24] reviewing that classic forwarding schemes do not take into consideration the charachteristics of the THz communications which can have a bad impact in the network performance, proposed a channel-aware forwarding scheme. The overcome of the frequency selective feature of the THz band is achieved via judicious selection of the next-hop node. The selection of the next hop considers the balance between minimizing the frequency selective feature and the hop count to reach the destination. The drawback is that by selecting the next-hop node computational complexity is added to each node. In the present work we assume a simple forwarding scheme transmitting the data to all nodes that are inside the transmission range.

Networks-on-chip (NoCs)

Similarities also exist among the studied nanonetworks and ad hoc networks-on-chip (NoCs) [1]. NoCs need to discover their topology and perform defect mapping [6]. Looping paths among chips is another major concern, which can be mitigated in various proposed ways, such as virtual channels [2] and spanning trees [17]. An overview of the NoCs routing algorithms can be found in [17]. Nonetheless NoCs assume much more powerful nodes than nanonetworks, even able to support a full protocol stack [19, 23]. Concluding NoC-oriented solutions generally can not be implemented on nanonetworks.

Categories of ad hoc routing protocols

Generally ad hoc routing protocols can be divided in two main categories based on their underlying architectural framework as follows in (Fig. 1).

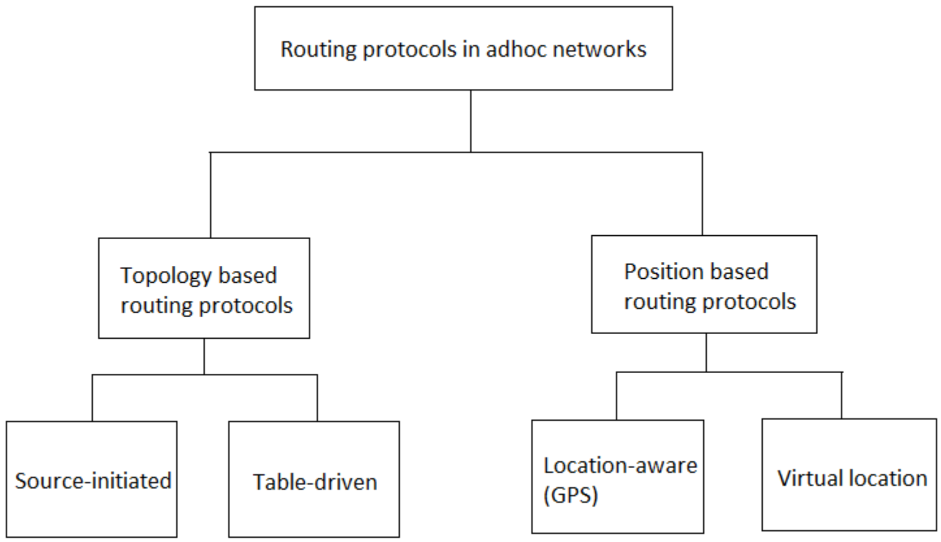

Figure 1: Categories of ad hoc routing protocols

The first main category is based on the specific topology of the network by discovering and storing data about it. The position based routing protocols try to calculate the routing path by determining the location of the nodes.

Source-initiated routing represents a class of routing protocols where the route is created only when the source requests a route to a destination. The route is created through a route discovery procedure which involves flooding the network with route request packets are flooded to starting with the immediate neighbors of the source. This discovery procedure by flooding the network require a lot of energy every time a sender wants to sent a packet, so it can't satisfy our need for low power consumption on nanonetworks.

Table driven routing protocols always maintain up-to-date information of routes from each node to every other node. Routing information is stored in the routing table of each node and route update packets are propagated throughout the network to keep the routing information as updated as possible. In this case the need for information storing require a lot of memory which isn't a nanonode's characteristic.

Location-aware routing schemes in ad hoc networks assume that the individual nodes are aware of the locations of all the nodes within the network. The best and easiest technique is the use of the Global Positioning System (GPS) to determine exact coordinates of these nodes in any geographical location. This location information is then utilized by the routing protocol to determine the routes. The most common problem on location-aware routing schemes is looping a packet between a set of nodes. This is resulting into a dead-lock a situation where the packet can not continue its routing path. Also the calculation of the exact location on nanonetworks require high accuracy computations and metric units, which adds high complexity. Ko and Vaidya present Location-aided routing (LAR) [14, 15] protocol which utilizes location information to minimize the search space for route discovery towards the destination node. Basagni et al. propose the DREAM [4] protocol which also uses the node location information from GPS systems for communication. GPSR [13], by Karp and Kung, also uses the location of the node to selectively forward the packets based on the distance.

Virtual location based routing schemes are the most close approach to our work on nanonetworks. This is because the computation of the routing path is based on virtual coordinates which means less accuracy, but easy calculations and low comlexity. The authors in [7] proposes a virtual coordinates based routing (VCR) scheme. A location-free point-to-point routing scheme, called virtual domain and coordinate routing (VDCR) is proposed in [9]. Another virtual location based routing scheme can be found in [8].

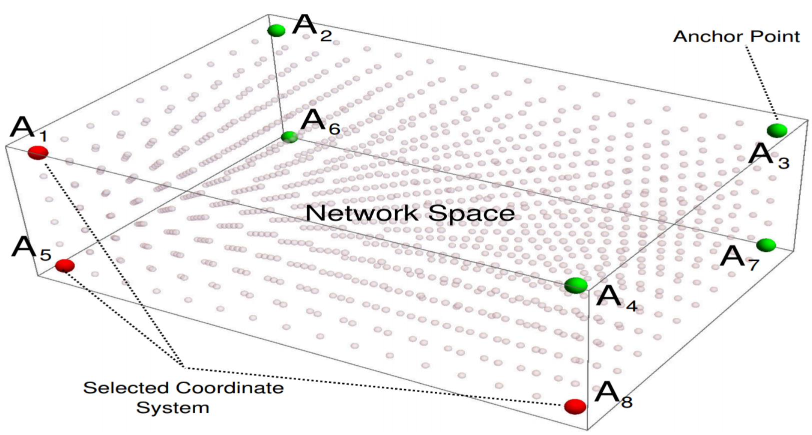

Figure 2: Overview of the nanonetwork.

Nanonode Addressing

The studied nanonetwork topology assumes a set of nodes placed in a 3D rectangle (Fig. 2). The nanonodes in the 3D space can be placed with a certain pattern or randomly, also the space can have a particular or a random number of nodes. Nodes do not differ from each other, there are only eight "special" nodes called "anchors",which are placed at the vertexes of the rectangle. These anchors have a certain role in the node addressing phase. During the virtual location initialization of the network we assign an address to each node, which is it's 3D location calculated by each node distance (in hops) from the eight anchors.

$$Location \leftarrow (nhops_a, nhops_b, nhops_c, nhops_d, nhops_e, nhops_f, nhops_g, nhops_h)$$

where nhops a,b,c,d,e,f,g,h is the node distance in hops from each anchor.

In more detail the addressing phase starts with the first anchor (A1) broadcasting a data packet with the following structure, a setup flag set to 1 to show the initialization phase, the anchor index set to 1 for A1 and the hop count set also to 1. Then each recipient of the packet ckeck if the packet has been received again by the same anchor and decides to keep it or drop it. If the packet is reserved the hop count is memorized as the distance from the certain anchor, then the hop count is incresed by +1, and the packet is brodcasted again by the node. We allow a trivial timeout to ensure that the propagation is completed and then the same procedure occures for the other anchors. At the end of this phase each node has obtained its address as the hop distances from the eight anchors. It is noted that the address of each node is not unique, this is because an address refers to a certain area rather than one node.

Routing Schemes

In this section we describe each routing scheme.

Anchor_Pair_3 : Assuming a sender node P1 and a receiver P2, the sender selects three indexes out of the eight anchors to serve as the coordinate system (CS) for the packet delivery towards P2. To ensure that there is always a valid path between the sender and receiver the three selected anchors must be on the same side of the rectangle. Therefore there are 24 valid coordinate system options (4 on each side of the space).

The optimal coordinate system is selected as follows:

$cs \leftarrow \arg\min\{|nhops\_s_a - nhops\_r_a| + |nhops\_s_b - nhops\_r_b| + |nhops\_s_c - nhops\_r_c|\}$

where nhops_s and nhops_r is the number of hops for the sender and receiver, and a,b,c is one of the 24 possible anchor triplets.

The info is stored in the header of the packet with the following structure:

setup flag (1 bit)	Packet id (8 bits)	CS (3x3 bits)
P1 Address	P2 Address	DATA

where packet id is a random integer, and DATA is the usefull data that the sender want to deliver.

At the reception of a packet, the node checks if a packet with the same id has been already received and at this case decides to drop it. Else, it memorizes the packet id to be able to avoid route loops, decides if its address is on the right path to the destination based on the CS and retransmits the packet.

Anchor_Pair_4: This scheme has no limitation in the possible cases while selecting four anchors indexes out of eight to serve as the coordinate system for the packet delivery towards the receiver.

The optimal coordinate system is selected by calculating the value of:

|nhops_s − nhops_r|

where nhops_s and nhops_r is the number of hops for the sender and receiver.

We select the four smallest values out of eight, the selected values are representing the anchors of the optimal coordinate system. By selecting a four anchor CS we reduce the mass of the routing path on the 3D space because the condition that every node uses to decide if it has to retransmit considers an additional anchor in comparison with Anchor_Pair_3.

The same structure applies for the header packet, only the size of the coordinate system (CS) change to (4x3 bits).

setup flag (1 bit)	Packet id (8 bits)	CS (4x3 bits)
P1 Address	P2 Address	DATA

Anchor_Pair_4+: In this scheme we also select the indexes of four anchors out of eight to serve as the coordinate system. The three anchors of the optimal coordinate system are selected with the same way as in Anchor_Pair_3, and the fourth is the anchor that exists on the same side of the rectangle. Therefore there are 6 valid coordinate system options (one on each side of the rectangle).

Simulations

For the evaluation, we assume a 3D topology where 7225 nodes are uniformly distributed in a rectangle, with dimensions 750 x 500 x 500 mm or 25 x 17 x17 nodes.

With an interval time of 500 nsec we randomly select a sender and a receiver among the nodes. The sender sends a single packet, which is transferred to the receiver in a manner defined by each compared routing schemes. We repeat this process for 1000 random pairs. The experiment parameters are summarized in Table 1.

Parameter	Value
Number of experiments	1000
Interval Transmition Time	500 ns
Number of nanonodes	7225
Topology Dimension	750 x 500 x 500 mm
Layout	3D Grid Rectangle
Routing Protocols	FLOODING, AP3, AP4, AP4+

Table 1: Simulation Parameters

Flooding : this is the most naive routing scheme and it is included in this work as an upper limit of performance. Each node retransmits every packet it receives without any condition.

Performance Metrics

In this section we define the performance metrics used at our experiments.

Average Number of Retransmiters:

$AverageRetransmiters = {}^{TotalRetransmiters}/_{g}$
where g is the number of experiments.

Total Retransmitters: number of nodes that retransmitted at least a packet on one experiment.

Average Number of Lost Packets:

$AverageLostPackets = {}^{TotalLostPackets}/_{g}$
where g is the number of experiments.

Total Lost Packets: the aggregate lost packets over all nodes and over all exchanges

$TotalLostPackets = \sum_{k=1}^{k=g} (\sum_{i=0}^{i=n} LostPackets_i)_k$
where LostPackets is the number of lost packets of the i nanonode, n is the number of nanonodes and g is the number of experiments.

Average Number of Received Packets:

$AverageReceivedPackets = {}^{TotalReceivedPackets}/_{g}$
where g is the number of experiments.

Total Received Packets: the aggregate received packets over all nodes and over all exchanges

$TotalReceivedPackets = \sum_{k=1}^{k=g} (\sum_{i=0}^{i=n} ReceivedPackets_i)_k$
where ReceivedPackets is the number of received packets of the i nanonode, n is the number of nanonodes and g is the number of experiments.

Average Transmission Time:

$AverageTransmissionTime = {}^{TotalTransmissionTime}/_{g}$
where g is the number of experiments.

Total Transmission Time:

$TotalTransmissionTime = \sum_{i=0}^{i=n} TransmissionTime_i$
where TransmissionTime is the amount of time from the beginning until the end of a message transmission and n is the number of experiments.

Results

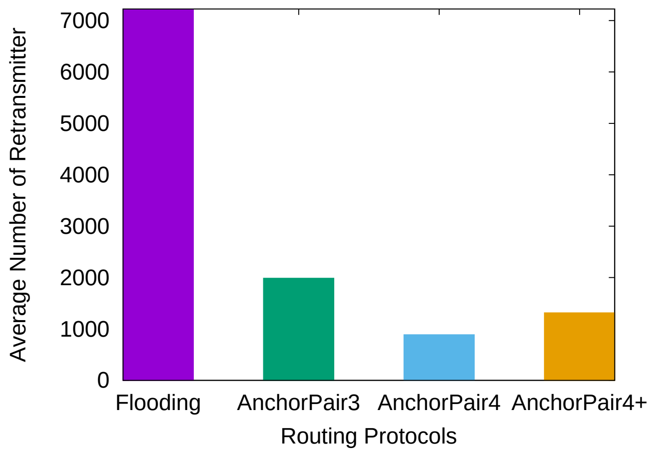

Figure 3: Average number of retransmitter

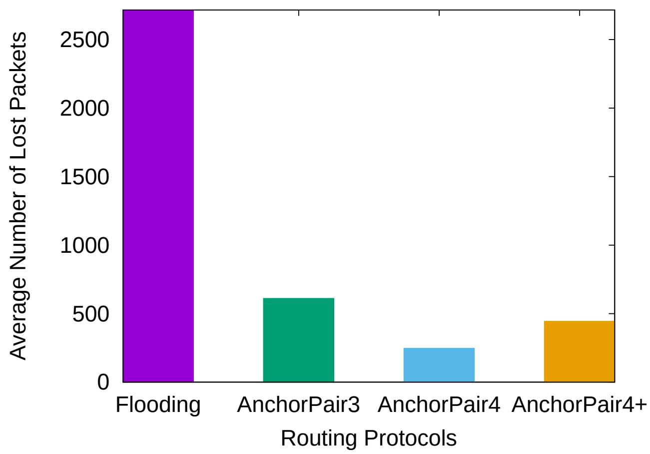

Figure 4: Average Number of Lost Packets

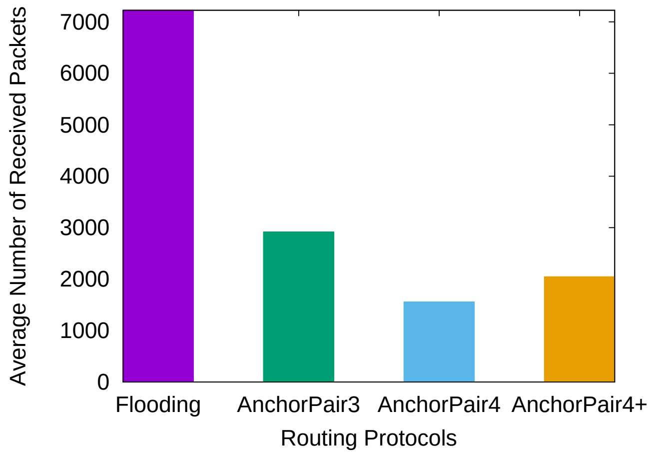

Figure 5: Average number of Received Packets

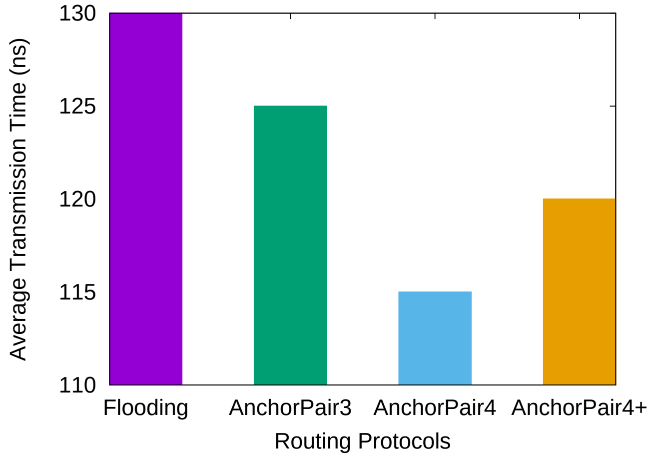

Figure 6: Average Transmission Time

Comments on results

- Anchor Pair 4 achieves 50 % reduction on average number of retransmitters in comparison with Anchor Pair 3 (Fig. 3).
- Anchor Pair 4 has a total improvement because less packet retransmissions means less traffic on the network leading to a faster transmition (Fig. 6).
- The limitation in selection of anchors in Anchor Pair 4+ concludes to a indermediate solution between Anchor Pair 3 and Anchor Pair 4.

- Anchor Pair 3 header packet is smaller than Anchor Pair 4 because of the smaller CS (3x3 bits), so it can carry more usefull DATA, but the speed of propagation is reduced.

Conclusion

This work introduced three new routing schemes for 3D nanonetworks. The addressing procedure in all three schemes is the same as in the work of CORONA by computing each nodes distance in hops from a set of anchor points. The routing algorithms differ from each other because they choose a different set of anchor points while calculating the routing path. Anchor Pair 4 acheives better performance than Anchor Pair 3 because of an additional anchor in the proccess of finding the routing path. Also the selection of the appropriate anchors requires less calulations on Anchor Pair 4 than Anchor Pair 3 leading to less computation complexity. Evaluation experiments showed reduced retransmissions and low transmission time.

References

[1] S. Abadal, M. Iannazzo, M. Nemirovsky, A. Cabellos-Aparicio, H. Lee, and E.Alarcon. On the area and energy scalability of wireless networkonchip: A model-based benchmarked design space exploration. *IEEE/ACM Transactions on Networking*, 2014.

[2] A. Abbas, M. Ali, A. Fayyaz, A. Ghosh, A. Kalra, S. U. Khan, Muhammad Usman Shahid, T. d. Menezes, S. Pattanayak, A. Sanyal, and S. Usman. A survey on energy-ecient methodologies and architectures of network-on-chip. *Computers & Electrical Engineering*, 2014.

[3] I. F. Akyildiz and J. M. Jornet. Electromagnetic wireless nanosensor networks. *Nano Communication Networks*, 2010.

[4] S. Basagni, I. Chlamtac, V.R. Syrotiuk, and B.A. Woodward. A distance routing effect algorithm for mobility (dream). *Proceedings of the ACM MOBICOM*, 1998.

[5] P. Boronin, V. Petrov, D. Moltchanov, Y. Koucheryavy, and J. M. Jornet. Capacity and throughput analysis of nanoscale machine communication through transparency windows in the terahertz band. *Nano Communication Networks*, 2014.

[6] V. Catania, A. Mineo, S. Monteleone, and D. Patti. Distributed topology discovery in self-assembled nano network-on-chip. *Computers & Electrical Engineering*, 2014.

[7] Min Chen, Xiaodan Wang, Victor C.M. Leung, and Yong Yuan. Virtual coordinates based routing in wireless sensor networks. *Sensor Letters ISSN: 1546-198X*, 2006.

[8] Tony Grubman, Y. Ahmet Sekercioglu, and Nick Moore. Virtual localization for robust geographic routing in wireless sensor networks. *Volume 8629 of the series Lecture Notes in Computer Science pp 179-186*, 2015.

[9] Chih-Cheng Hsu, Cheng-Fu Chou, Kate Ching-Ju Lin, and Chien-Chun Hung. Virtual domain and coordinate routing in wireless sensor networks. *WCNC*, 2009.

[10] J. M. Jornet and I. F. Akyildiz. Channel modeling and capacity analysis for electromagnetic wireless nanonetworks in the terahertz band. *IEEE Transactions on Wireless Communications*, 2011.

[11] J. M. Jornet and I. F. Akyildiz. Joint energy harvesting and communication analysis for perpetual wireless nanosensor networks in the terahertz band. *IEEE Transactions on Nanotechnology*, 2012.

[12] J. M. Jornet, J. Capdevila Pujol, and J. SolAl' Pareta. Phlame: A physical layer aware mac protocol for electromagnetic nanonetworks in the terahertz band. *Nano Communication Networks*, 2012.

[13] B. Karp and H. Kung. Gpsr: Greedy perimeter stateless routing for wireless networks. *Proceedings of ACM MobiCom*, 2000.

[14] Y. Ko and N. Vaidya. Location-aided routing (lar) in mobile ad hoc networks. *Proceedings of ACM MobiCom*, 1998.

[15] Y.-B. Ko and N.H. Vaidya. Geotora: A protocol for geocasting in mobile ad hoc networks. *Proceedings of IEEE ICNP*, 2000.

[16] S. Mohrehkesh and M. Weigle. Rih-mac: Receiver-initiated harvesting-aware mac for nanonetworks. *ACM ICNCC*, 2014.

[17] J. P. Patwardhan, C. Dwyer, A. R. Lebeck, and D. J. Sorin. Evaluating the connectivity of self-assembled networks of nano-scale processing elements. *IEEE International Workshop on Design and Test of Defect-Tolerant Nanoscale Architectures*, 2005.

[18] G. Piro, G. Boggia, and L. Grieco. On the design of an energyharvesting protocol stack for body area nano-networks. *Nano Communication Networks*, 2015.

[19] Ville Rantala, Teijo Lehtonen, and Juha Plosila. Network on chip routing algorithms. *TUCS Technical Report No 779*, 2006.

[20] A. Tsioliaridou, C. Liaskos, S. Ioannidis, and A. Pitsillides. Corona: A coordinate and routing system for nanonetworks. *Nano Communication Networks*, 2015.

[21] A. Tsioliaridou, C. Liaskos, L. Pachis, S. Ioannidis, and A. Pitsillides. N3: Addressing and routing in 3d nanonetworks. *International Conference on Telecommunications (ICT)*, 2016.

[22] B. D. Unluturk, D. Malak, and O. B. Akan. Rate-delay tradeoff with network coding in molecular nanonetworks. *IEEE Transactions on Nanotechnology*, 2013.

[23] M. Younis, I. F. Senturk, K. Akkaya, S. Lee, and F. Senel. Topology management techniques for tolerating node failures in wireless sensor networks: A survey. *Computer Networks 58*, 2014.

[24] Hang Yu, Bryan Ng, and Winston K.G. Seah. Forwarding schemes for embased wireless nanosensor networks in the terahertz band. *Nano Communication Networks*, 2015.